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Real Options and Portfolio Models in R&D Project Selection

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REAALIOPTIOT JA PORTFOLIOMALLIT TUOTEKEHITYSPROJEKTIEN VALINNASSA

TUTKIMUKSEN TAVOITTEET

Tutkielman tutkimusongelma on: ”Miten reaalioptioita ja portfoliomalleja voidaan käytännössä käyttää tuotekehitysprojektien valinnassa?” Tuotekehitysprojekteihin liittyvät reaalioptiot ovat arvokkaita, sillä ne antavat johdolle mahdollisuuden reagoida sattumanvaraisiin tulevaisuuden tapahtumiin. Portfoliomallit puolestaan tukevat johtoa tuotekehitysportfolion tasapainottamisessa.

Työn päätavoite on kaventaa eroa teorioiden ja käytännön välillä. Lisäksi tutkimus pyrkii yhdistämään reaalioptioiden arvonmäärityksen ja portfoliomallit.

RAKENNE JA TUTKIMUSMENETELMÄT

Tutkielma pyrkii konstruktiivisen tutkimusotteen kautta rakentamaan käytännössä toimivia päätöksenteon apumalleja. Tutkielma koostuu kirjallisuuteen perustuvasta teoriaosasta sekä empiirisestä osasta. Teoriaosa on jaettu kahteen pääkappaleeseen. Näistä ensimmäinen käy läpi laajasti reaalioptioihin liittyvää kirjallisuutta. Kappale pyrkii löytämään helposti ymmärrettävän menetelmän tuotekehitysprojekteihin liittyvien reaalioptioiden arvonmääritykseen. Jälkimmäinen kappale käsittelee projektiportfolion johtamista yleensä ja erityisesti portfoliomalleja.

Empiirinen osa perustuu havaintoihin, jotka tehtiin aktiivisesti uusiin teknologioihin panostavassa case-yrityksessä. Tutkimuksen aikana tutkielman laatija työskenteli yrityksessä, mikä mahdollisti ihanteelliset olosuhteet mallien kehittämiselle ja palautteen saamiselle.

TULOKSET

Tutkimuksessa kehitetyt mallit ovat tutkielman merkittävin ansio. Tämän lisäksi tehtiin joukko yleisiä havaintoja. Ensinnäkin havaittiin, että reaalioptioiden käytännön soveltaminen edellyttää yksinkertaistusten tekoa. Lisäksi todettiin, että vain sellaiset mallit, jotka voidaan ymmärtää, voivat toimia päätöksen tukena. Portfoliomalleista puolestaan havaittiin, että mikään yksittäinen malli ei riitä, vaan tarvitaan joukko toisiaan tukevia malleja.

AVAINSANAT

Reaalioptiot, reaalioptioiden arvonmääritys, projektiportfolion hallinta, portfoliomallit, reaali-investoinnit, tuotekehitysprojektien valinta

HELSINKI SCHOOL OF ECONOMICS
Department of Accounting and Finance
Master's Thesis
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ABSTRACT

2002-11-18

REAL OPTIONS AND PORTFOLIO MODELS IN R&D PROJECT SELECTION

RESEARCH OBJECTIVES

The research problem of the study is: "How can real options and portfolio models be used in practical R&D project selection?" Real options are valuable in R&D projects as they provide managers the opportunity to respond to future contingent events. Portfolio models, on the other hand, support managers in balancing the R&D project portfolio.

The main objective of the study is to bridge the gap that exists between the theory and practice. In addition, the study attempts to bring together real option valuation and portfolio models.

STRUCTURE AND RESEARCH METHODS

The study uses a constructive approach to build decision support tools that function in practice. The report is composed of a theoretical part, which is based on literature, and an empirical part. Furthermore, the theoretical part is divided into two main chapters. The first of these chapters covers a wide range of real option literature. The chapter aims at finding an easily understandable method for the valuation of real options in R&D projects. The latter chapter discusses the theory of project portfolio management in general and portfolio models in particular.

The empirical part is based on findings made in a case company, which is very active in making R&D investments in new technologies. At the time of the study, the author was employed by the company, which provided an ideal setting for developing the models and getting instant feedback on them.

RESULTS

The main contribution of the study is the models that were developed. However, some general findings were also made. First, it was found that in order to apply real option theory in practice, some simplifying assumptions have to be made. Second, only models that can be understood can be used to support decision making in practice. Third, the use of a single portfolio model is not enough. Several models that support each other are needed.

KEYWORDS

Real options, real option valuation, project portfolio management, portfolio models, capital investments, R&D project selection

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1 Introduction

1.1 Background

The allocation of limited resources among research and development (R&D) projects is one of the most difficult managerial decisions (see, e.g., Roussel et al. 1991, and Tritle et al. 2000). It is also one of the most important decisions, as the costs of R&D are rising and most companies are increasingly dependent on new technology for competitive advantage (see, e.g., Nixon 1998, and Cooper et al. 1998). R&D project selection methods are used to support managers in making this fundamental decision.

R&D project selection entails project evaluation. Over one hundred R&D project evaluation methods are described in literature and many more are used in practice (EIRMA 1995). Traditional methods often fail in providing satisfactory decision support and, consequently, more sophisticated methods are constantly developed. In particular, the application of real options in capital budgeting has attracted a growing interest (see, e.g., Busby et al. 1997). In addition to evaluating individual projects by applying the theory of real options, it has become more widely agreed that the best projects are most likely to be selected if all the projects are considered as a portfolio.

At least conceptually, the theories of real options and project portfolio management seem to provide better answers to the resource allocation problem compared to traditional methods. However, theory is one thing but practice can be quite another. Although some success stories of implementing one or both of the aforementioned theories exist, a lot of work remains to be done if the theories are to be accepted by the majority of practitioners.

The main contribution of this study lies in bridging the gap between theory and practice. The study aims at building practical decision support tools that utilize real option valuation and portfolio models. The tools are developed for a case company to ensure that they are useful in practice.

Another contribution of this study is that it brings together the two theories, which have so far been studied jointly only by a few authors. Including the dimension of real option value into portfolio evaluation gives both academics and practitioners a new opportunity to tackle the complex problem of R&D project selection.

1.2 Research Problem and Objectives

The main research problem of this thesis can be stated as a question:

"How can real options and portfolio models be used in practical R&D project selection?"

R&D project selection refers to the evaluation of existing research and development projects in order to recommend supporting the best projects and downscaling the rest (Bordley 1998). Typically, the selection has to be done under some resource constraints, such as limited financial and people resources (Chun 1994).

Real options are options associated with investment opportunities that are not financial instruments. An option, in turn, is the right but not the obligation to take an action in the future. Consequently, Kogut and Kulatilaka (2001) define real option as an "investment in physical assets, human competence, and organizational capabilities that provide the opportunity to respond to future contingent events".

Portfolio models in the research problem refer to the wide range of different models, whose main goal is to balance the project portfolio of a company. In addition, the models help to maximize the value of the portfolio, and to align the portfolio with the company's strategy (Cooper et al. 1998, p. 19 – 20, 81).

In order to answer the research problem, the following four objectives were set. First, the study tries to identify common problems encountered in R&D project selection. The identification includes discussion on the characteristics of R&D in general, and a review of existing R&D project evaluation methods. The second objective is to describe the real option theory and to discuss real option valuation in practice. Third, the study introduces the theory of project portfolio management, focusing especially on portfolio models. Finally, the fourth objective is to test the theories in practice by developing R&D project selection tools for a case company. Figure 1-1 illustrates the research problem and the objectives of the study.

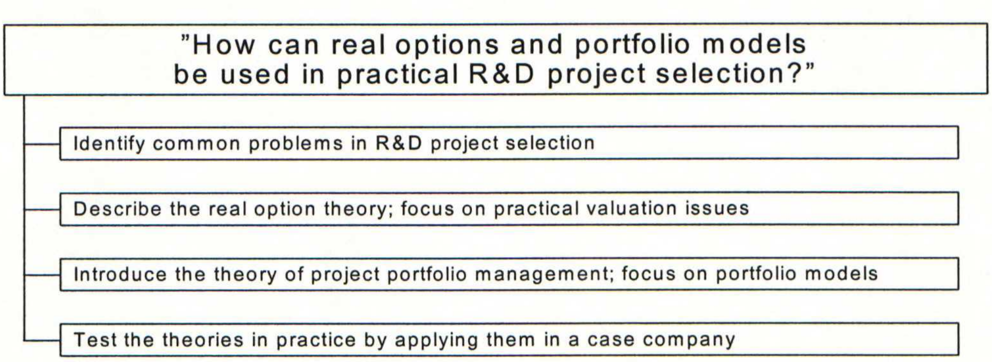

Figure 1-1 Research problem and objectives

1.3 Scope of the Study

This study is about making R&D management more effective through improved R&D project selection. However, R&D project selection is only one of the many key factors associated with effective R&D management (Bordley 1998). Important other knowledge areas and skills include, for instance, understanding customer needs, monitoring market developments, working with other organizational functions, and technology commercialization capabilities (Gupta et al. 2000). To keep a clear focus and to stay closer to the management accounting discipline, these other important factors are not considered in the study.

R&D project selection is not the same as R&D investment process. In fact, project selection is a stage in the more comprehensive investment process. A generic framework for capital investment process will be described in order to emphasize the difference. The investment process will be discussed shortly also in various other parts of the study. However, designing and implementing a new investment process would be a very extensive work that could take years to complete (Cooper et al. 1998, p. 183 – 204). Therefore, the improvement of the whole process is not in the scope of this study, although admittedly a well-functioning process is essential for successful R&D project selection in practice.

The real option theory is presented relatively broadly but only little emphasis is put on continuous-time models and interactions among multiple option types. The mathematics involved in continuous-time and interacting options are much more complex than in discrete-time and non-interacting options. As the study aims to build models that are easy to use and understand, the scope is narrowed to option types that involve less sophisticated mathematics. Besides, the option valuation used in this study can often be used to approximate options of higher complexity.

Project portfolio management is approached from the perspective of actual models used to support decision-making. Other perspectives, such as process perspective, which is related to the capital investment process, or organizational considerations are not in the scope of the study, although a short introduction to the theory of project portfolio management will be given.

Finally, portfolio models that are the most important to this study aim primarily to balance the portfolio, and only secondarily to maximize the value of the portfolio, or to align the portfolio with strategy.

1.4 Research Methodology

The study uses a constructive research approach to answer the research problem. Constructive approach is a research procedure, which intends to solve practical problems through the construction of, for example, organizational procedures, models, diagrams, or plans. Figure 1-2 summarizes the essential elements of a constructive research approach. (Kasanen et al. 1993a)

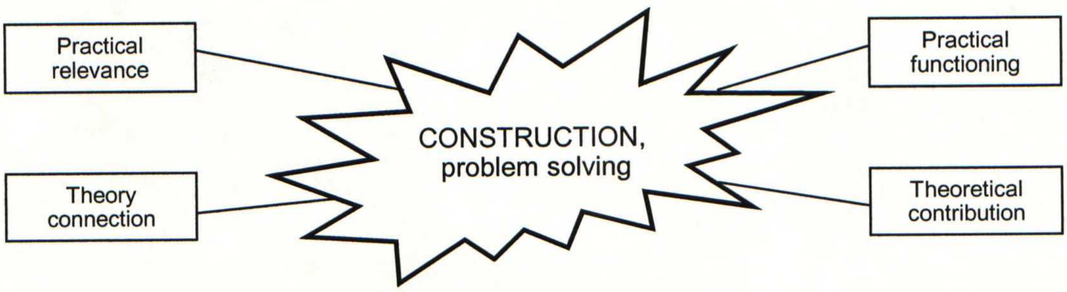

Figure 1-2 Elements of constructive research (Kasanen et al. 1993a)

In short, a constructive study produces an innovative solution to a practically relevant problem. A successful solution works in practice, and is relevant, simple, and easy to use. Moreover, its theoretical connections are demonstrated. Kasanen et al. (1993a) argue that such a solution fulfills the most significant general characteristics of science, such as objectivity, criticalness, autonomy, and progressiveness. Thus, a successful construct can also contribute to theory.

As already mentioned, the study – like constructive research approach itself – has two basic aspects: theoretical and practical. The theory included in the theoretical part of the thesis is approached through a literature study. The literature includes journal articles and widely recognized books on capital budgeting, options and real options, and project portfolio management.

The practical part of the thesis builds on the findings of the theoretical part. In the practical part, models for improving R&D project selection are developed partly based on the underlying theories and partly based on free innovation. The models are developed in close co-operation with practitioners, and the empirical findings are reflected back to theory, both of which are important features of the constructive research approach (Lukka 2000).

It should be noted that the information shown in the practical part of the study does not represent the actual situation or business of the case company. The project portfolio is hypothetical, and used only to illustrate the models developed for the case company. Moreover, the findings, interpretations, and conclusions are the author's own and do not necessarily represent the view of the case company.

1.5 Structure of the Report

The thesis report is composed of six chapters. The structure of the report is as follows:

- Chapter 1 is the introductory chapter.
- Chapter 2 gives an overview of R&D project selection. The chapter discusses some of the characteristics of R&D, which are relevant in project selection. In addition, the chapter reviews methods that are the most commonly used in R&D project evaluation.
- Chapter 3 describes the theory and valuation of real options. The chapter concentrates on issues that are the most relevant in practical applications.
- Chapter 4 introduces the theory of project portfolio management. Parts of the theory are discussed only briefly as the focus is on various portfolio models that are used in the portfolio management process.
- Chapter 5 tests the theories presented in previous chapters in practice. The chapter presents a model for evaluating individual R&D projects using real options, and ten portfolio models. The models are applied in a case company, which provides feedback on their practical usefulness.
- Chapter 6 presents the results of the study in a concise form. In addition, it includes discussion on the limitations of the study and recommendations for further research.

2 R&D and the Capital Investment Process

This chapter starts by defining the basic terms and concepts used in the chapter and the rest of the report. The second section presents a generic capital investment process, which aims to clarify what exactly is meant by R&D project selection and how the selection is related to the whole investment process. The third section gives a review of the most common R&D project evaluation methods. Finally, some common problems in R&D and R&D project selection are discussed

2.1 Definitions

This section defines the basic terms R&D and investment, and several related terms. These terms, and R&D in particular, are often loosely used. Although research and development are often bundled together and considered synonymous, they have different meanings. For example, international accounting standards (IAS) in financial accounting make a difference between the terms.[1] As R&D investments are in the focus of this study, a closer inspection of the terms is warranted.

A general definition for research and development is that they comprise creative work undertaken typically on a systematic basis in order to increase knowledge and to use this knowledge to devise new applications. More specifically, R&D covers three activities: basic research, applied research, and experimental development. (OECD 1994, p. 13)

Basic research is experimental or theoretical work, in which the primary goal is to acquire new knowledge without any particular application or use in view. Applied research has the same goal of acquiring new knowledge. However, in contrast with basic research, applied research is directed towards a specific practical objective. Experimental development, or development for short, draws on existing knowledge gained from research and possibly from practical experience. It is directed towards producing new materials, products, and processes, or improving those already existing. (OECD 1994, p. 13)

There are many possible definitions for newness. According to Cooper (1993, p. 11 – 13), new products and processes can be new in two dimensions. The first dimension

[1] According to IAS 38, all research costs are expensed. In contrast, development costs are capitalized after technical and commercial feasibility of the asset for sale or use has been established.

is newness to the company in the sense that the company has not previously made or sold a particular product although other companies might have done so. The second dimension is newness to the market, or innovativeness, in which the product or process is the first of its kind on the market. Moreover, products can be new in both dimensions simultaneously, and the level of newness can vary from low to high.

In addition to R&D, investment is another commonly used, yet rarely defined, term. In economics, investment has traditionally been defined as the act of incurring an immediate cost in the expectation of future rewards (Dixit & Pindyck 1994, p. 3). From this definition it follows that R&D can be considered an investment as resources invested in R&D today are expected to yield future benefits. The resources and benefits should be considered in a wide sense as they can include more than just monetary assets. For example, benefits may be realized in the form of new knowledge. In addition, a company that shuts down a loss-making facility is also investing. The payments the company has to make to extract itself from contractual commitments related to the facility are the initial cost, and the expected reward is a reduction in future losses.

According to Dixit and Pindyck (1994, p. 3), most investment decisions share three important characteristics in varying degrees. These three characteristics interact to determine the optimal investment decision. First, the investment is partially or completely irreversible. This characteristic is related to sunk costs: the initial investment is usually, at least partially, sunk and cannot be recovered. Second, the future rewards are uncertain. In other words, the evaluation of an investment has to be done using more or less subjective probabilities of alternative outcomes. Third, the timing of the investment is flexible to some extent. For instance, it is often possible to postpone an investment to get more information about the future.

Capital investments are investments in real assets[2] used in the operations of a company. Capital investment decisions are reached through a process known as the capital investment process, or the capital budgeting process. According to Drury (1996, p. 383), the capital budgeting process is concerned with determining which specific investment projects a company should accept, determining the total amount

[2] There is an endless variety of both tangible and intangible real assets. Tangible real assets include, for example, machinery, factories, and offices; intangible real assets include, for example, technical expertise, trademarks, and patents. (Brealey & Myers 1996, p. 3)

of capital expenditure, and determining how the portfolio of projects should be financed. This process will be discussed next.

2.2 Capital Investment Process

As already mentioned in the introduction, the focus of this study is on R&D project selection, which refers to the evaluation of existing research and development projects in order to recommend supporting the best projects and downscaling the rest (Bordley 1998). However, project selection cannot be done in isolation from the capital investment process that encompasses more stages than just the selection. This section looks at the whole process in more detail.

During the past few decades, behavioral accounting research has provided several models for the capital investment process. Empirical findings indicate that the process is complex and often non-linear, with significant overlap and numerous links between the stages of the process (Kasanen et al. 1993b, p. 22). Nevertheless, the models have attempted to divide the process into a varying number of distinct stages.

For example Pinches (1982), who draws on the work of Mintzberg et al. (1976), defines a model that consists of four stages: identification of investment opportunities, development of initial ideas into project proposals, selection of projects for implementation, and control of the performance of the selected projects. On the other hand, Horngren et al. (2000, p. 748 - 749) describe six stages: identification, search, information-acquisition, selection, financing, and implementation and control. Although there are a different number of stages, the underlying process is relatively similar in most of the models found in literature.

Pike and Neale's (1999, p. 192 - 203) capital budgeting model is shown in Figure 2-1. The model divides the capital investment process into four main stages. The starting point is the determination of the budget, in which it is decided how much can be spent in total. The second stage is the search for, and development of, projects. This stage is followed by the evaluation stage, which results in the authorization for projects that pass the evaluation criteria. Finally, approved projects enter the monitoring and control stage.

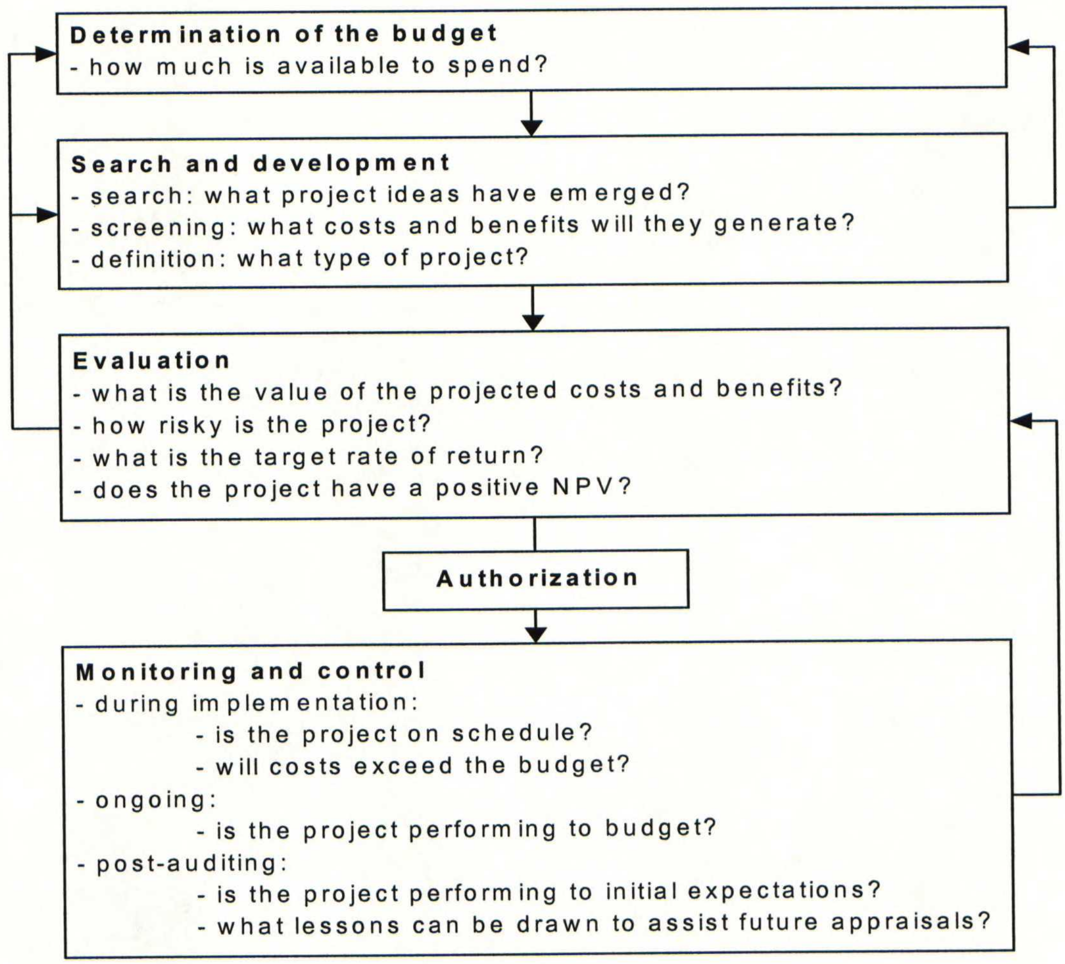

Figure 2-1 A simple capital budgeting system (Pike & Neale 1999)

Normative investment theory separates investment decisions and financing decisions. In theory, a capital project could raise funding from the capital market based on the prospective returns and the riskiness of the project. Therefore, normative theory has concentrated on the costs of financing and the respective rate of return required from an investment. (Kasanen et al. 1993b, p. 55)

However, in practice, the funding in multi-divisional organizations comes from the organization's internal capital market in which there is better information for assessing capital project proposals and allocating resources. The managers who control the internal capital market set the limits on how much is available to spend on projects in each unit that makes capital investments. (Pike & Neale 1999, p. 194)

The budget imposed by the managers may be more or less rigid depending on the organization. It can be argued that the budget should not be completely frozen. The subsequent stages may give reason to reassess the budget and to reallocate funds in order to support the best available projects.

The search and development stage that follows the budget stage can be considered the most critical stage in the capital investment process. In practice, it is the organization's ability to innovate and produce good project ideas that defines the success of the organization's investment efforts. No accounting system can help if good ideas do not emerge. (Kasanen et al. 1993b, p. 26)

At this early stage, the screening of investment ideas should be only preliminary. Full-scale evaluation is not feasible and, in many cases, not even possible due to poor quality of data available. The ideas can be screened against the fit with the organization's strategy, technical feasibility, resource requirements, rough market potential, and the estimated risk-level. The aim is to filter out projects that clearly are not worth of further investigation. (Pike & Neale 1999, p. 194 – 195)

The last step in the search and development stage is to properly define the project, which has so far been a more or less vague idea. This step involves the collection of data to describe the technical and economic characteristics of the project. Alternative ways to proceed with the proposal should be generated and appraised to find the most attractive combination of the characteristics. (Pike & Neale 1999, p. 195 – 196)

The evaluation and authorization stage involves appraisal of the project and decision outcome, such as accept, reject, or request further information. The next section will describe various project evaluation methods. That section focuses on R&D projects, but the same methods may also be used in the evaluation of other capital projects.

The monitoring and control process includes both pre-decision and post-decision controls. Pre-decision controls influence managerial behavior at an early stage in the capital investment process. Examples of pre-decision controls are setting authorization levels and procedures, setting goals, and identifying strategic areas for growth. Post-decision controls include the monitoring of ongoing projects and post-audit procedures. (Pike & Neale 1999, p. 199)

An important part of the monitoring and control stage is the post-completion audit. Post-audit aims to compare the actual performance of a project with the forecast made at the time of approval. According to Pike and Neale (1999, p. 200 – 201), post-auditing may encourage more thorough and realistic appraisals of future projects. It may also facilitate the control of on-going projects.

Finally, it is important to note that the capital investment process is not only financial in nature. It is also a social process, which includes various strategic, administrative, organisatory, political, and behavioral aspects. The aim of project evaluation is not always to objectively compare investment opportunities. Often there is already a strong commitment to the project being evaluated, in which case the assessment is used just to confirm and document the investment decision, which may have already been made. (Kasanen et al. 1993b, p. 10 – 25)

2.3 Evaluation of R&D Projects

To support the selection of the best R&D projects, the projects have to be evaluated. According to one definition, R&D evaluation means assessing the benefits from R&D relative to the resources needed as a basis for decision making. In addition, R&D evaluation can be considered a means of communication between those who carry out the R&D and those who will apply the results. (EIRMA 1995, p. 57) Systematic project evaluation methods are also useful because they can raise new questions, interest new parties, and increase involvement in the organization (Cabral-Cardoso & Payne 1996).

Various methods and techniques for R&D project evaluation, or selection, have appeared in the literature for at least forty years. A thorough list of references to earlier literature is presented by Hall and Nauda (1990), and a more recent overview is given by Henriksen and Traynor (1999). A very comprehensive review has been published by European Industrial Research Management Association (EIRMA 1995).

As is evident in the literature, there is no single taxonomy for R&D project evaluation methods. Figure 2-2 presents a classification, which is a synthesis of the aforementioned three reviews as well as the classifications used by Archer and Ghasemzadeh (1999), Cooper et al. (1998), and Gustafsson and Salo (2001).

Most of the R&D project evaluation methods can be used not only for evaluating individual projects but also for portfolio analysis. In fact, it is very difficult to separate the evaluation of individual projects from the evaluation of a project portfolio, although these two can be seen as different tasks. To emphasize both aspects, Figure 2-2 illustrates the range of uses for each category. Most methods, perhaps with the exception of checklists and vision, can be applied to portfolio analysis, whereas only mathematical programming cannot be used in the evaluation of individual projects.

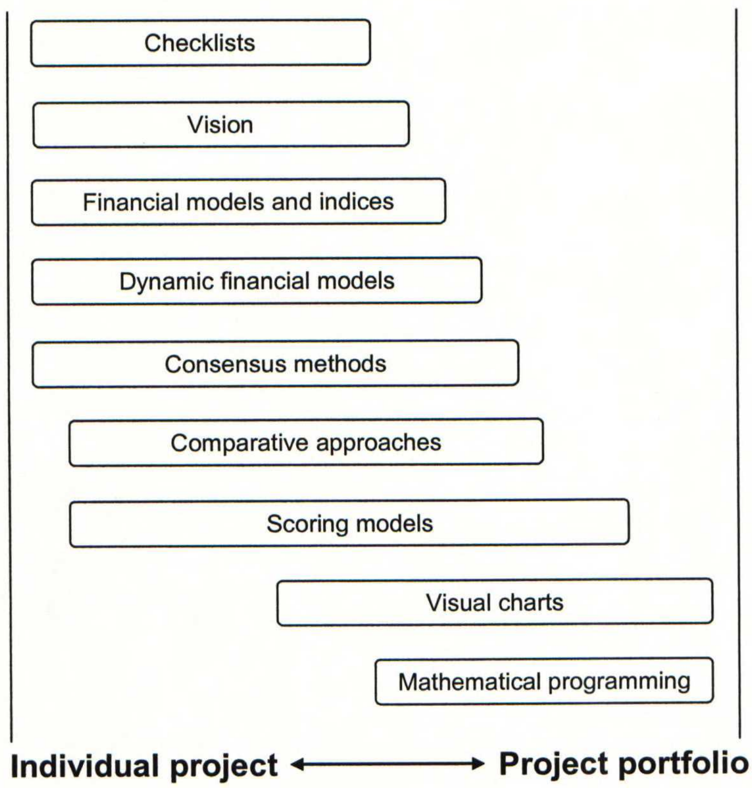

Figure 2-2 R&D project evaluation methods

Checklists are used to discard projects that fail to meet the checklist criteria. A checklist typically includes several critical questions, which are answered with a straight yes or no. A single negative answer is enough to kill a project. Although checklists may be an efficient method for discarding poor projects, they are not useful as a portfolio tool because they do not rank the surviving projects. (Cooper et al. 1998, p. 52 – 53)

Vision is the instinct and judgment of an individual, who is typically a senior manager or a product champion. Using vision is a speedy and low-effort method for making decisions on individual R&D projects when information is scarce. A person may support his vision by asking for peer reviews. The main disadvantages of vision are that it can sometimes be nothing more than a wild guess as it is not supported by any rational methods, and it does little to improve communication between the R&D and management. (EIRMA 1995, p. 38)

Financial models and indices range from discounted and non-discounted cash flow methods to various ratios, such as return on investment (ROI), and indices, which are usually derived from cash flow methods or ratios. Financial models and indices are widely discussed in, for example, basic textbooks on corporate finance and investment (see, e.g., Brealey & Myers 1996), and they are also popular in practice.

Dynamic financial models try to incorporate the structure of consecutive decisions and uncertainties in an individual R&D project. The two most common approaches are decision trees and real options. The focus of dynamic financial models has traditionally been on individual projects. (Gustafsson & Salo 2001)

Consensus methods aim at encouraging a group of managers and experts to achieve consensus about a given topic. The most famous consensus method is the Delphi method, in which experts are pushed towards consensus through successive rounds of questionnaires, which are answered anonymously (Spinelli 1983).

Comparative approaches include methods such as Q-Sort, paired comparison, and Analytic Hierarchy Process (AHP). Like consensus methods, comparative approaches aim at achieving group consensus. The projects are rank-ordered according to paired comparisons. A major disadvantage is the large number of comparisons, which makes it difficult to use these approaches for comparing a large number of projects. (Archer & Ghasemzadeh 1999)

Scoring models have historically been used for making individual project decisions. However, these classical scoring models have been modified and adapted to become relevant also for portfolio selection. (Cooper et al. 1998, p. 13)

A scoring model includes factors that are believed to be important in evaluating projects. These factors typically include financial figures as well as criteria that are more subjective. Each project in the portfolio is scored on each factor, and each score is multiplied by an importance weight attached to the respective factor. The weighted sum of scores is the project score. The project score can be used both to evaluate individual projects and to prioritize projects in a project portfolio. (Archer & Ghasemzadeh 1998)

Visual charts include a multitude of matrices, bubble diagrams, histograms, bar charts, and pie charts, which aim at visually displaying the balance in R&D portfolios. Visual charts can be very useful if chosen with care. The selection of which dimensions are used in matrices and bubble diagrams, and which parameters are shown in charts, is obviously critical. (Cooper et al. 1998, p. 81)

Mathematical programming refers to various optimization techniques such as linear, nonlinear, integer, goal, and dynamic programming. The objective of optimization models is to develop a portfolio of new and existing R&D projects that maximizes some objective function, subject to a set of resource constraints. A typical objective function is the total benefit, which can be expressed, for example, as the net present value or the expected profits. (Cooper 1993, p. 171; Luenberger 1998, p. 102 – 103)

According to Gustafsson and Salo (2001), the main advantage of optimization models is that, in theory, they can be used to solve complex problems with project interdependencies and resource constraints. However, these methods are not widely used because they have considerable – and often overwhelming – data requirements. The required data includes information on the financial results, resource needs, timing, and probabilities of completion and success for all projects. Much of this information is typically unreliable, or perhaps not available at all. (Cooper 1993, p. 172)

The portfolio models that are developed in this study are based on visual charts. They can be used to present the results of other evaluation methods effectively. Portfolio models will be discussed in more detail in Chapter 4.

2.4 Common Problems in R&D

Figure 2-3 illustrates typical problems encountered in R&D and causes to these problems. Cooper et al. (2000) identify three root causes of the problems: a lack of resources for new products, no portfolio management process, and no new product process.

According to Cooper et al. (2000), resource availability is rarely a part of the financial calculations used to evaluate individual R&D projects. The lack of resources for new products can lead to too many and too small projects. The resulting negative effects may include lower quality of execution, insufficient information on projects, and stress. It may also take longer time to reach the market, which is especially critical in many high technology industries.

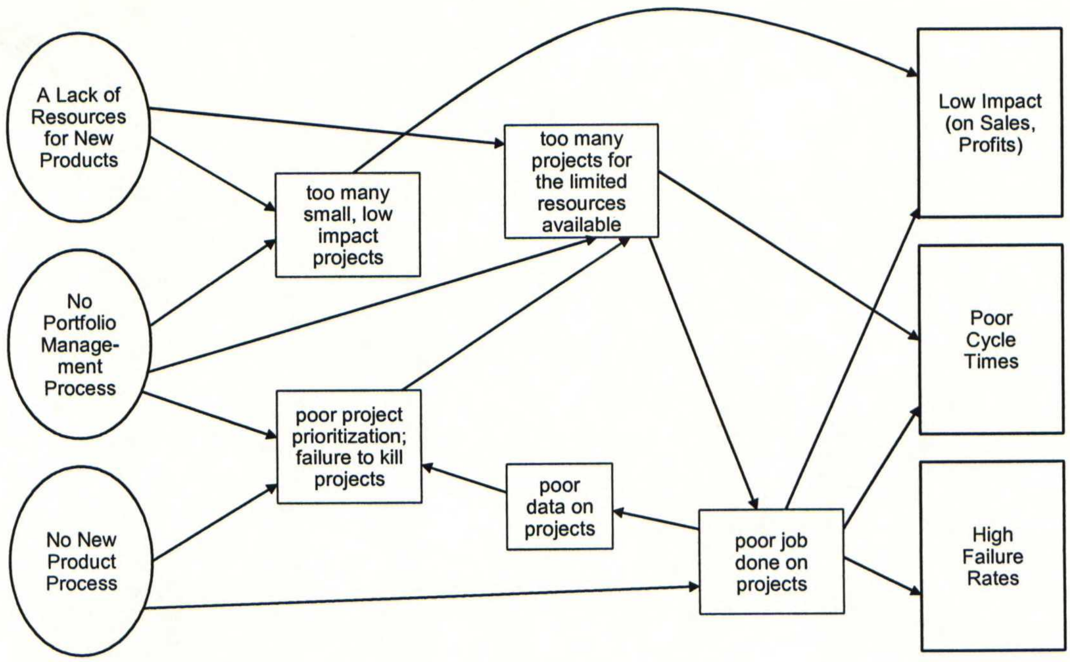

Figure 2-3 Root causes of problems in R&D (Cooper et al. 2000)

R&D investment budget is not the only resource limit. Other resources, such as people resources, can also be a limiting factor. In addition, when evaluating R&D projects, it may be necessary to consider also resources in, for example, production or marketing, which may be needed later on in a project's life.

The situation in which there are too many projects may also be caused by the lack of portfolio management. This cause is also likely to lead into problems in project prioritization. A common problem is that managers are not prepared to "walk away" from an R&D investment when they should. Sometimes projects are abandoned only when financial conditions force to do so.

According to Faulkner (1996), R&D projects develop inertia of their own and are therefore difficult to stop. Bard et al. (1998) note that the consequences of continuing an R&D project when its failure is imminent go beyond the lost investment expenditure. The human and material resources wasted on the project may be critically needed elsewhere. For example, some projects may fail to receive the needed resources to pass a critical stage, apparently healthy projects may begin to deteriorate without additional resources, or promising new projects may have to be unnecessarily deferred. Efficient project portfolio management can help managers to see when a project needs to be abandoned and, thus, can help to alleviate the problem.

It is also important to have a clear new product process. When the quality of early stage work is better, an excellent foundation is laid for the project. This can result in better product design, better testing, and better launch and production start-up. In addition, when the early work is done better, market and technical information on the project is of higher quality. Better information helps managers to select the winning projects, which results in a better portfolio. (Cooper et al. 2000)

An additional problem in R&D is that the evaluation of R&D projects is often difficult. Loch and Bode-Greuel (2001) identify three reasons for this. First of all, the future is always uncertain and, hence, not all possible contingencies or courses of action are known. Second, quantitative economic estimates are difficult to make and are often subject to significant uncertainty. Finally, R&D is characterized by continued corrective actions based on new information as the future unfolds. Traditional methods have failed to quantify the value of this flexibility. Real options, which attempt to do this, are discussed in the next chapter.

3 Real Options in R&D Project Selection

This chapter begins by briefly introducing the basic option concepts. The second section shows the analogy between real options and financial options. The third section describes various types of real options, and the fourth compares real options with net present value (NPV) method, and decision trees. In the fifth section, the discussion shifts to the valuation of real options. Finally, the chapter explains how the valuation parameters can be estimated in practice.

3.1 Basic Option Concepts

The history of options goes back to ancient times, as already the Greek philosopher Aristotle recorded the story of Thales the Milesian, who amassed a fortune by buying options on the use of olive presses (Aristotle 350 BC, Book One, Part XI). Since then, and perhaps even before that time, options have been used for various purposes. However, greater interest towards options did not emerge until 1973, when the world's first formalized options market, the Chicago Board Options Exchange, began listing call options (Bodie et al. 1999, p. 608) and Fischer Black and Myron Scholes published the first reasonable mathematical method for the pricing of options (Black & Scholes 1973).[3]

An option is the right, but not the obligation, to buy or sell an asset at a specified price within a predetermined time. An option giving the right to purchase something is called a call option, whereas an option giving the right to sell something is called a put option. (Brealey & Myers 1996, p. 558 - 559)

The specifications of an option include whether it is a call or a put option, an exercise price, an expiration date, and the description of the underlying asset. The exercise price, or strike price, is the price at which the underlying asset can be purchased or sold upon the exercise of the option The expiration date defines the period of time for which the option is valid. (Luenberger 1998, p. 320)

There are two primary conventions regarding the exercise date of an option. If an option can be exercised only on the expiration date, it is called a European option.

[3] Myron Scholes and Robert Merton, who collaborated with Black and Scholes, shared the 1997 Nobel Prize in Economics for discovering the method. The prize would undoubtedly have been shared with Fischer Black had he not died two years earlier.

An option, which can be exercised at any time before and including the expiration date, is known as an American option. (Luenberger 1998, p. 320)

Typical underlying assets of options include financial instruments such as stocks and bonds. According to Brealey and Myers (1996, p. 557), options can also be on stock indices, foreign exchange, and physical assets. Furthermore, some banks may be prepared to tailor-make options of higher complexity.

In addition to the four above-mentioned specifications – call or put, exercise price, expiration date, and the underlying asset – an option has a certain price, which can be either negotiated as a part of the option contract or established by the market. The party that purchases the option pays the price, or premium, to the party that writes the option. (Luenberger 1998, p. 320 – 321)

The party that makes the purchase faces no risk of loss other than the original price. However, the party that writes, or grants, the option faces a larger risk of loss, since this party must buy or sell the underlying asset if the option is exercised. In the case of an exercised call option, the writer may have to sell the asset at a price much lower than the current market price, and in the case of an exercised put option, the writer may have to buy the asset at a price much higher than the current market price. (Luenberger 1998, p. 321)

An option is said to be in the money when its exercise would produce profits for its holder and out of the money when exercise would be unprofitable. Moreover, if the exercise price is equal to the asset price, the option is at the money. For example, a call option is out of the money when the exercise price is below the asset price. However, even though immediate exercise of the option would be unprofitable, the option retains a positive value if there is a chance that the asset price will increase sufficiently by the expiration date to allow for profitable exercise. (Bodie et al. 1999, p. 610 – 611, 656).

Figure 3-1 illustrates the value of a call option before its expiration date. The dashed line represents the actual value of the option, and the heavy line represents the intrinsic value, which is the value of the option if exercised immediately. The difference between the actual value and the intrinsic value is called the time value of the option[4]. The time value is attributable to the fact that the option still has positive time to its expiration. (Bodie et al. 1999, p. 656)

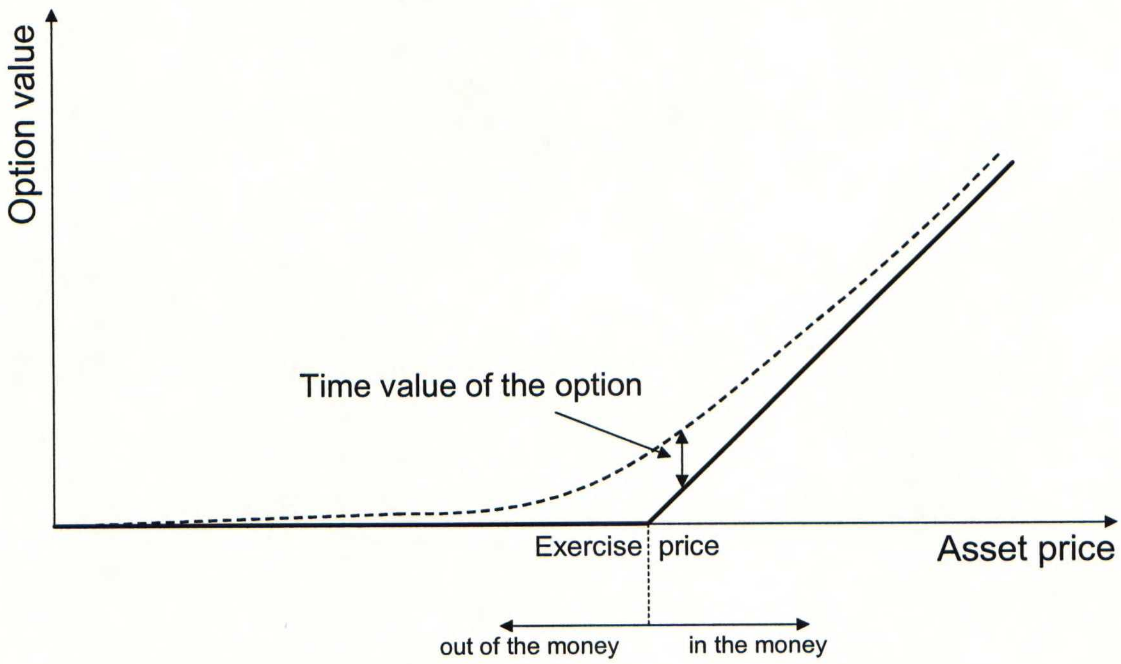

Figure 3-1 Value of a call option before expiration date (Bodie et al. 1999)

A call option is always worth more than its value if exercised now – unless the underlying asset is completely worthless, in which case the option is also worthless. The time value of an option is the highest when the option is approximately at the money. Even when a call option would be worthless if exercised immediately, it still has a positive value because there is potential for a profit if the price of the underlying asset increases before the expiration date. (Bodie et al. 1999, p. 656)

When the asset price is substantially higher compared to the exercise price, the value of a call option approaches the asset price less the present value of the exercise price. This is because the higher the asset price, the higher the probability that the option will eventually be exercised. If it is virtually certain that the option will be exercised, it is effectively the same as owning the asset now. The difference is that the asset will be paid later on, and the present value of this obligation is the present value of the exercise price. (Brealey & Myers 1996, p. 570)

When the asset price is substantially lower than the exercise price, a call option becomes nearly worthless because the probability that it will ever be exercised is

[4] This should not be confused with the time value of money!

minimal. The probability of exercise is dependent on the volatility in the underlying asset price and the time to expiration. If volatility is high, there is more upside potential. Good performance may result in the option expiring in the money, whereas bad performance cannot worsen the payoff below zero. Because of this asymmetry, higher volatility increases the value of an option as shown in Figure 3-2.

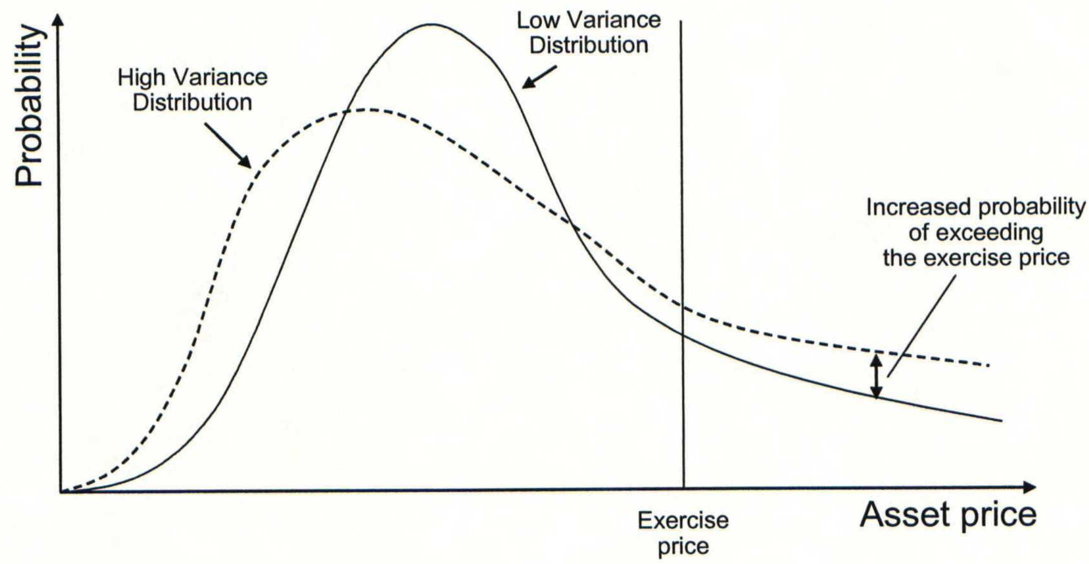

Figure 3-2 Higher volatility increases the value of an option (Copeland & Antikarov 2001)

A longer time to expiration increases the value of a call option. During a longer period of time, the range of likely asset prices increases, and there is more time for unpredictable events to affect the asset price. In addition, a longer time to expiration decreases the present value of the exercise price, which also increases the value of a call option. However, for a put option, the impact of longer time to expiration is ambiguous, because lower present value of the exercise price reduces the value of the option. (Bodie et al. 1999, p. 658)

In addition to the volatility of the asset price and the time to expiration, the value of an option depends on the asset price, exercise price, and interest rate. In addition, stock options may be affected by the dividend payout policy of the firm. Table 3-1 summarizes the factors affecting the value of call and put options, ceteris paribus.

The effects of asset price changes and exercise price changes to the value of a call option are straightforward. Clearly, an increase in the asset price increases the value of a call option, as can be verified from Figure 3-1. On the other hand, an increase in the exercise price decreases the value of a call option because it directly lowers the optionholder's potential profit. For a put option, the effects are the reverse.

Table 3-1 Factors affecting the value of call and put options

Increase in factor	Call option	Put option
Current asset price	+	-
Exercise price	-	+
Time to expiration	+	+/-
Volatility	+	+
Risk-free interest rate	+	-
Dividend yield	-	+

Interest rate affects the present value of the exercise price. A rise in interest rates increases the value of a call option by decreasing the present value of the exercise price, whereas a fall decreases the option's value. Dividend payouts decrease the value of a call option because a higher dividend yield implies a lower expected rate of capital gains. Again, for a put option, the effects of changes in interest rate and dividend yield are the reverse.

3.2 Comparison of Financial Options and Real Options

The applicability of option theory is not limited to financial assets alone. Real options, also known as capital investment options, are option-like features found in capital budgeting decisions. According to Pike and Neale (1999, p. 345 – 346), options are created in capital investment projects by managerial flexibility. In other words, corporate managers hold options because they can take actions to mitigate losses or exploit new opportunities presented by capital investments.

The term real option already implies that option theory can – and should – be used in their valuation (Luenberger 1998, p. 341). Consequently, real options are usually approached with the same methods used to price options on financial assets.

However, when the treatment of options in financial markets is extended to real options, some problems arise. In the case of real options, the underlying asset is typically not a traded asset as in the case of financial options. Therefore, for valuation purposes, the underlying asset is often replaced with another asset whose price process is closely related to the price process of the underlying asset. The problem is that, according to Hubalek and Schachermayer (2001), it is impossible to obtain a perfect replication of the real option by trading only a closely related asset. This does not, however, lead to the presented valuation methodology being incorrect but it does add an error term that depends on the correlation coefficient between the underlying asset and the closely related asset. The quantification of this error term is a complex task and not in the scope of this study. Nevertheless, it is important to be aware of that perfect replication of a real option is usually not achievable.

According to Copeland and Antikarov (2001, p. 111), another important difference between financial and real options is that most financial options are issued by independent agents and not by the company on whose shares they are written. Therefore, the issuer has no control over the share price. Real options are different because management controls the underlying asset. If the company is able to enhance the value of the underlying asset, the value of the real option is in most cases enhanced.[5]

Table 3-2 illustrates the close analogy that exists between a real investment opportunity and a call option on a share. Similarly to an owner of an American call option, which gives the right – but not the obligation – to acquire the underlying share by paying the exercise price on or before the expiration date, the owner of an investment opportunity has the right – but not the obligation – to acquire the present value of expected project cash flows by making an investment outlay before the investment opportunity disappears. This kind of a real option is called an option to defer. (Trigeorgis 1998, p. 124 - 125)

Table 3-2 Comparison between a financial call option and a real call option (Pike & Neale 1999)

Financial call option on a share	Real call option on a project
Current value of share	Present value of expected cash flows
Exercise price	Investment cost
Time to expiration	Time until investment opportunity disappears
Share price uncertainty	Project value uncertainty
Risk-free interest rate	Risk-free interest rate

When other real options in addition to the option to defer the investment are present, the investment opportunity can be seen as a call option on a portfolio, which consists of the project's net present value and the other real call or put options (Trigeorgis 1998, p. 125). Various types of real options are introduced in the following section.

[5] In the case of option to defer, the value of the real option may fall.

3.3 Taxonomy of Real Options

There is no one way to classify real options. This is not surprising as a great variety of real options exist. Consequently, a common approach in literature is to describe the most common types of real options instead of exhaustively classifying all possible types. For example, Brealey and Myers (1996, p. 589 – 610) describe four types of real options[6], whereas Copeland and Keenan (1998a) classify seven types of real options into growth options, deferral/learning options, and abandonment options[7].

One of the most widely recognized categorizations of real options is shown in Table 3-3. The table divides real options into six categories, according to which companies have options to defer, options to stage investment, options to alter operating scale, options to abandon, options to switch outputs or inputs, and growth options. In addition, Trigeorgis (1998, p. 18 – 19) identifies multiple interacting options, which involve a collection of various other options. Real-life projects often involve a collection of options, whose combined value may – and usually does – differ from the sum of separate option values.

Table 3-3 Common types of real options (adapted from Trigeorgis 1998)

Category	Description	Important in
Option to defer	An opportunity to wait and see if prices develop favorably in the future. For example, management holds a lease on valuable land or resources. It can wait to see if output prices justify constructing a building or a plant, or developing a field.	All natural resource extraction industries; real-estate development; farming; paper products
Time-to-build option (staged investment)	Staging investment as a series of outlays creates an option to abandon the project in midstream if new information is unfavorable. Each stage can be viewed as an option on the value of subsequent stages and valued as a compound option.	All R&D-intensive industries, especially pharmaceuticals; long-development capital-intensive projects (e.g., large-scale construction or energy-generating plants); start-up ventures
Option to alter operating scale	If market conditions are more favorable than expected, the firm	Natural-resource industries (e.g., mining); facilities planning and

6 These four real options are: the option to make follow-on investments if the immediate investment project succeeds, the option to abandon a project, the option to wait (and learn) before investing, and the option to vary the firm's output or its production methods.

7 Growth options include the options to scale up, switch up, and scope up; deferral/learning options include the option to study/start; and abandonment options include the options to scale down, switch down, and to scope down.

	can expand the scale of production or accelerate resource utilization. Conversely, if conditions are less favorable than expected, it can reduce the scale of operations. In extreme cases, production may be halted and restarted.	construction in cyclical industries; fashion apparel; consumer goods; commercial real estate
Option to abandon	If market conditions decline severely, management can abandon current operations permanently and realize the possible resale value of capital equipment and other assets.	Capital-intensive industries (e.g., airlines, railroads); financial services; new-product introductions in uncertain markets
Option to switch (e.g., outputs or inputs)	If prices or demand change, management can change the output mix of the facility. Alternatively, the same outputs can be produced using different types of input.	*Output shifts:* Any good sought in small batches or subject to volatile demand (e.g., consumer electronics); toys; specialty paper; machines parts; cars *Input shifts:* All feedstock-dependent facilities; electric power; chemicals; crop switching; sourcing
Growth options	An early investment is a prerequisite or a link in a chain of interrelated projects, opening up future growth opportunities.	All infrastructure-based or strategic industries – especially high tech, R&D, and industries with multiple product generations or applications (e.g., computers, pharmaceuticals); multinational operations; strategic acquisitions

According to Kulatilaka and Marcus (1992, p. 96), the timing of investment is the most common real option embedded in an investment opportunity. The option to defer allows the management of a company to wait and see how the price of the underlying asset develops in the future. The option to defer has recently been studied by, for example, Arya and Glover (2001), Farzin et al. (1998), Laughton (1998), McGrath (1997), and Lee (1997).

Rarely do capital investment opportunities require that all funds be invested immediately. In contrast, most investments take considerable time to build and have a limited rate of investment with which to proceed. (Majd & Pindyck 1987) In other words, the required capital is invested as a series of outlays over time, which creates an option to terminate the project at each stage (Trigeorgis 1998, p. 10 – 11). R&D is a typical investment of this type. Time-to-build options, or staged investment options, have been studied by, for example, Sing (2002), Bar-Ilan and Strange (1998), and Ott and Thompson (1996).

Options to alter operating scale allow companies to adjust to changes in market conditions. In favorable conditions, the scale of operations can be expanded and, conversely, the scale can be reduced in unfavorable conditions. Options to alter operating scale have been studied by, for example, Bollen (1999), Cortazar and Casassus (1998), and Kamrad (1995).

In declining market conditions, management may have a valuable option to abandon the project permanently. In some cases, some salvage value may be received in return. A seminal paper on the option to abandon has been authored by Myers and Majd (1990), while more recent papers include research by Lavin and Zorn (2000), Davis (1998), and Laughton (1998).

Options to switch are valuable when prices or demand change. They provide flexibility to switch from the current input to the cheapest future input, or from the current output to the most profitable future output. This flexibility can be achieved via technology or, for example, by maintaining relationships with a variety of suppliers. (Trigeorgis 1998, p. 13) Options to switch have been studied by, for example, Van Mieghem (1998), Childs et al. (1996), and Kulatilaka and Trigeorgis (1994).

Options to switch should not be confused with a real option type called switching options. Some authors (e.g., Copeland & Antikarov 2001, p. 17 - 18) use the latter term to describe options giving the right to close and reopen an operation. In the categorization used in this study, these switching options are a subclass of options to alter operating scale.

Growth options embedded in many pilot investments set the path for future opportunities. The pilot project itself may appear unattractive but it may be a necessary link to subsequent projects that, in time, will be profitable. Recently published studies on growth options include papers from Loch and Bode-Greuel (2001), Berk et al. (1999), and Kulatilaka and Perotti (1998).

R&D projects can include several types of real options. There can be an option to defer if the project has not yet been started. If market conditions decline during the project, the option to abandon may become valuable. Moreover, if the R&D investment consists of series of outlays over time, then each stage of the project can be seen as an option on the value of the next stage. Finally, various growth options may be embedded in R&D projects.

3.4 Real Options, Net Present Value, and Decision Trees

Numerous investment appraisal methods can be found in literature and in practice. These include discounted cash flow approaches, such as net present value and internal rate of return, and non-discounting methods, such as payback method and various accounting rates of return. It is widely accepted in literature that the net present value method is the superior one and conceptually sound (see, e.g., Brealey & Myers 1996, p. 85 – 106; Pike & Neale 1999, p. 129 – 150). This section considers net present value from the perspective of real options. In addition, classic decision tree analysis, which is often used for investment appraisal, is briefly discussed at the end of the section.

Net present value has its shortcomings. A practical problem is that the value is completely dependent on the expected future cash flows. Especially when considering R&D projects, the cash flow estimates can be very uncertain resulting in highly unreliable NPVs. One manager, who was interviewed for this study, commented that in these circumstances it is possible to adjust the figures to show whatever is wanted.

In addition to the aforementioned and other practical problems[8] with the net present value method, a theoretical point can also be made. The discounted cash flows used in NPV implicitly assume that companies hold their real assets passively. The value that managers can add to those assets by responding to changing circumstances or new information is not taken into account. It can be argued that the true value of an investment should include the discounted value of future cash flows and the value of the real options embedded in the investment. (Brealey & Myers 1996, p. 591 - 592)

According to Dixit and Pindyck (1995), the NPV rule ignores the lost opportunity to wait when an irreversible investment is made. When a company decides to make an investment, it gives up the possibility of waiting for new information that might affect the attractiveness or timing of the investment. This lost option to wait is an opportunity cost that should be included as a cost of the investment.

To overcome these shortcomings of traditional NPV, Pike and Neale (1999, p. 349) suggest that the true NPV of a project undertaken today should be calculated as:

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[8] Discussion on practical shortcomings of NPV and other discounted cash flow approaches can be found, e.g., in Pike & Neale 1999, p. 188 – 191.

True NPV	=	NPV of basic project	+	NPV of abandonment option	+	NPV of follow-on projects	-	NPV of option to wait

In addition to the traditional NPV calculation, Pike and Neale have included three types of real options in the formula. The value of an abandonment option is based on the opportunity to divest a project early before heavy capital expenditure is incurred. The NPV of follow-on projects is based on the wealth-creating new opportunities that the basic project may create. Finally, the option to wait has value because valuable new information may be gained by delaying the project. The value of the option to wait is subtracted from the true NPV because the company surrenders this option by making the investment decision today.

A project creates wealth only if its true NPV is positive. The formula gives an explanation to why companies in practice sometimes defer projects with positive basic NPV or accept projects with negative NPV. In these cases, managers take into account – implicitly or explicitly – the value of the embedded real options. (Pike & Neale 1999, p. 349)

According to Copeland and Keenan (1998a), the value of real options should be taken into account especially under three conditions. First, when there is high uncertainty about the future, in which case it is very likely that new information will be received over time. Second, when managers have much room for managerial flexibility, which allows the management to respond to this new information. And third, when the NPV of the basic project is near zero. This is because if a project is neither obviously good nor obviously bad in the beginning, managers are more likely to take actions in the future. On the other hand, the value of real options is unlikely to affect decision-making if the NPV of the basic project is very high or strongly negative.

It can also be argued that real option calculations are valuable when a choice has to be made between competing investments. If both investments have a relatively same basic NPV value, the real option valuation can help in choosing the better investment opportunity.

Decision trees are used to calculate probability-weighted NPVs. Therefore, decision trees could be thought to be useful in the analysis of real options. However, it has been proved that the traditional decision tree analysis cannot be used in the valuation of options (see, e.g., Brealey & Myers 1996, p. 603 – 604, Copeland & Keenan

1998b). The main reason is that standard discounted cash flows used in decision trees simply do not work for options. There is no single, constant rate for options because the risk of an option changes as time and the price of the underlying asset change. If a decision tree contains meaningful future decisions, it also contains options, and thus option valuation techniques have to be used. The next section describes such techniques.

3.5 Valuation of Real Options

First, before going into how real options are valued, it should be noted that real options have value only if a company is truly prepared to act and exercise its options. Some critics (see, e.g., Fink 2001) say that the main problem with the theory is that it ignores the psychological and political realities of capital investments. A company does not necessarily have the capacity, a mechanism, or even will to exercise its options. For example, an option to abandon is worthless if, in reality, the company is not willing to divest a project once started.

Setting this criticism aside, there are several frameworks that can be used in the valuation of real options. The three main types are continuous-time models, finite-difference schemes, and lattice models. As will be presented, the first two types are of limited practical use and, consequently, the focus of this study is on lattice models. However, a short description of the former types is given first.

Most option pricing techniques do not explicitly predict future values of the underlying asset. In contrast, future values are assumed to follow a stochastic process that models the dynamics of the underlying asset value. The most commonly used process – both in theory and practice – is a geometric Brownian motion, which is a log-normal[9] process whose variance grows proportionally to the time interval. (Lander & Pinches 1998, p. 543)

It can be shown (see, e.g., Luenberger 1998, p. 351 – 355) that an option on an asset whose price is governed by a geometric Brownian motion must satisfy the partial differential equation

[9] A random variable is log-normally distributed if the logarithm of the random variable is normally distributed. Log-normal distribution, instead of normal distribution, is useful because it guarantees non-negative asset values.

$$\frac{\partial f}{\partial t}+\frac{\partial f}{\partial S}rS+\frac{1}{2}\frac{\partial^2 f}{\partial S^2}\sigma^2 S^2=rf\,,$$

where $f = f(S,t)$ is the price of the option, $S = S(t)$ is the price of the underlying asset, σ is the volatility of the underlying asset, r is the risk-free interest rate, and t is time. The proof rests on several assumptions, the most important of which is the arbitrage principle, which will be discussed later in this section. The equation is better known as the Black-Scholes equation.

In most cases, a continuous-time model entails the use of the Black-Scholes equation or a modification of the formula.[10] Unfortunately, these formulas work only for a limited number of option types and projects. For instance, American options, compound options, and projects with time-dependent parameters cannot be reliably valued by using the Black-Scholes equation or its modifications. (Lander & Pinches 1998, p. 543 – 544)

An alternative way to build a continuous-time model is to assume a given stochastic process for the underlying asset, and then derive and solve an appropriate partial differential equation. This task, which includes also the deriving of the necessary boundary conditions and constraints, leads often to highly complicated problems, which have no analytic solutions. The use of numerical approximation is therefore often required. (Lander & Pinches 1998, p. 544)

Finite-difference schemes are a method for numerically approximating the value of an option. The method is applicable to both European and American options but, like continuous-time models, it cannot handle some of the more complex option or project types. The general idea of the method is to convert the appropriate continuous-time differential equation into a set of discrete-time difference equations. These difference equations are then solved using an iterative backward process, which solves unknown values based on the known values of the subsequent periods. (Lander & Pinches 1998, p. 544)

Although finite-difference schemes are somewhat more intuitive and more widely applicable than continuous-time models, they also require a sophisticated knowledge

[10] One well-known modification is the Geske Model (Geske 1979), which has been adjusted for real option valuation by Kemna (1993).

of mathematics both to develop and to solve. In addition, they are usually difficult to implement and straightforward applications are few. (Lander & Pinches 1998, p. 545)

The use of continuous-time models or finite-difference schemes is quite uncommon in practice. In addition to implementation problems, the valuation is not intuitive and is difficult to understand by the majority of practitioners. Therefore, the rest of this section focuses on lattice models, which are easier to implement and more intuitive.

3.5.1 Option valuation using binomial lattices

Lattices can be used to model assets whose value changes discretely over a time interval. In addition, they can be used to numerically approximate continuous time processes. A lattice consists of a set of nodes and a set of arcs, which describe the branching between nodes. Normally there is a single root node, which branches to two or several other nodes, which in turn branch to other nodes. The most common lattices are binomial. In a binomial lattice, each node has exactly two branches.

A basic idea for the valuation of an option is to replicate the option with a portfolio that consists of an appropriate combination of the underlying security and a risk-free asset (Luenberger 1998, p. 360). This replicating portfolio is also called a synthetic option. In the case of a call option, the synthetic option is constructed by buying a particular number of shares of the underlying asset and by borrowing against them an appropriate amount at the risk-free rate. The number of shares, and the amount borrowed, should be selected so that the synthetic option exactly replicates the returns of the option in any future state of nature. (Trigeorgis 1998, p. 72 – 73)

Since the option and its synthetic equivalent will provide the same return irrespective of future events, they must sell for the same current price. This statement can be justified through the arbitrage argument, also known as the law of one price. If, for instance, the synthetic option were cheaper, it would pay to buy the synthetic option and to sell the normal option. This would create a risk-free arbitrage profit opportunity in which there would be instantaneous profit with zero investment. The profit would be the difference between the selling price of the normal option and the purchase price of the synthetic option. In addition, there would be no future consequence because the return from the synthetic option would offset the outlay of the sold option.

Although the arbitrage argument is an idealization including strong assumptions such as the absence of transaction costs, it is in practice a reasonable approximation (Luenberger 1998, p. 78). Therefore, it is possible to value an option by determining the cost of constructing its equivalent synthetic option. (Trigeorgis 1998, p. 73)

Binomial option valuation uses the arbitrage argument to price options (Luenberger 1998, p. 327 – 330; Trigeorgis 1998, p. 73 – 77). A binomial lattice can be used to model the option. Figure 3-3 shows three binomial lattices, which include two possible outcomes for the price of a stock, for the value of a risk-free asset, and for the value of a call option.

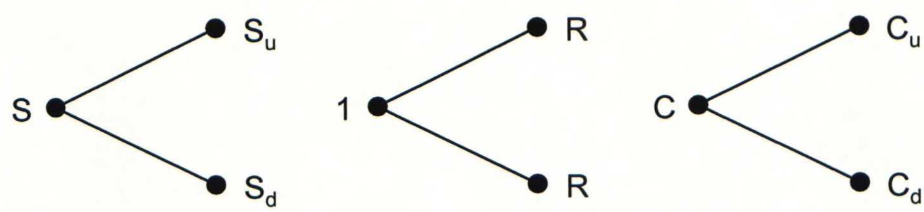


Figure 3-3 Binomial lattices for the stock price, the value of a risk-free asset, and the value of a call option

In the binomial lattices shown in Figure 3-3, S denotes the initial stock price. The stock price will move over the next period either up to S_u or down to S_d, with probabilities p and $1-p$, respectively. Risk-free interest rate is denoted with r, and R is short for $1+r$. C is the initial value of a European call option, whose future value depends on the stock price development and the exercise price K. More specifically,

$$C_u = \max(S_u - K, 0)$$

and $$C_d = \max(S_d - K, 0).$$

The three lattices shown in the figure all move together along the same arcs. In other words, if the stock price goes up, both the risk-free asset and the call option move along the upward arc as well. The value of the risk-free asset is, by definition, deterministic and thus the value is the same at the end of both arcs.

Now, to construct the synthetic option, N shares of the stock are bought at S, and amount B is borrowed at the risk-free interest rate r. The synthetic option has to offer the same return at the end of the period regardless of contingent future events. Therefore, to match the option outcomes, the following two equations must be satisfied:

$$NS_u - RB = C_u$$

$$NS_d - RB = C_d.$$

Solving these gives

$$N = \frac{C_u - C_d}{S_u - S_d}$$

and $$B = \frac{S_d C_u - S_u C_d}{(S_u - S_d)R}.$$

The cost of constructing the synthetic option can now be calculated as

$$C = NS - B = \frac{C_u - C_d}{S_u - S_d} S - \frac{S_d C_u - S_u C_d}{(S_u - S_d)R} = \frac{qC_u + (1-q)C_d}{R},$$

where $$q = \frac{RS - S_d}{S_u - S_d}.$$

The cost of constructing the synthetic option represents the value of a one-period call option on an asset, whose price is governed by a binomial lattice. The quantity q can be further simplified by defining $S_u = uS$ and $S_d = dS$, where $u > d > 0$. To avoid arbitrage opportunities, $u > R > d$ must hold (Luenberger 1998, p. 327). Now q can be simplified to

$$q = \frac{R - d}{u - d},$$

where $0 < q < 1$. Consequently, q can be considered a probability. A common interpretation is that q is a risk-neutral probability because the option value is calculated by taking the expected value using the probability q, and then discounting this value with the risk-free rate (Luenberger 1998, p. 329).

An important feature in the formula for the option value C is that the probability p of an upward move in the stock price does not affect the value. Moreover, the value of the option is independent of investors' attitudes towards risk or the characteristics of other assets. The value C can be found when there are estimates for the outcome of the stock price and the risk-free rate; there is no need to know the probability p or other factors (Trigeorgis 1998, p. 76).

A put option can also be valued similarly, except that in the case of the put option N shares of the underlying stock would be sold instead of bought, and amount B would be lent instead of borrowed (Trigeorgis 1998, p. 76). In fact, the procedure of valuation using the risk-neutral probability works – at least in theory – for all securities when applied correctly (Luenberger 1998, p. 329).

The single-period binomial lattice presented above can be extended to multiperiod options. Figure 3-4 shows a lattice for a two-period call option. In general, the value of a multiperiod option can be found by starting from the value of the option at the final nodes and working backward toward the initial node. In order to find the value at the final nodes, a lattice for the stock development has to be built first.

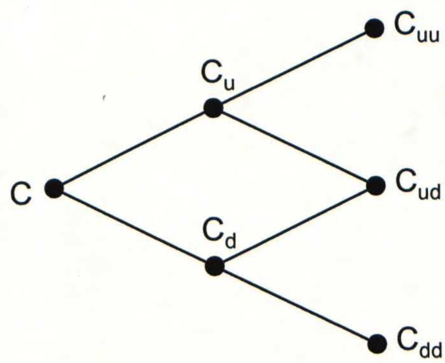


Figure 3-4 Lattice for a two-period call option

In the case of the two-period call option shown in Figure 3-4, the value of the option at the final nodes is

$$C_{uu} = \max(u^2 S - K, 0)$$
$$C_{ud} = \max(udS - K, 0)$$
$$C_{dd} = \max(d^2 S - K, 0).$$

If the option is not exercised early, the values C_u and C_d can be found by using the risk-neutral discounting formula. Therefore,

$$C_u = \frac{qC_{uu} + (1-q)C_{ud}}{R}$$

and $$C_d = \frac{qC_{ud} + (1-q)C_{dd}}{R}.$$

The assumption of no early exercise is realistic because the value of a call option before the final nodes is always greater than the amount that would be obtained from immediate exercise. (Luenberger 1998, p. 332 – 333)

3.5.2 Trinomial and other lattice models

It is also possible to use lattice structures of higher complexity to find the value of an option. For example, in a trinomial lattice each node branches to three other nodes. The trinomial lattice has more nodes than a binomial lattice in a given number of time periods, and thus it can produce a better approximation to the value of the option. Figure 3-5 shows a typical trinomial structure. (Luenberger 1998, p. 366)

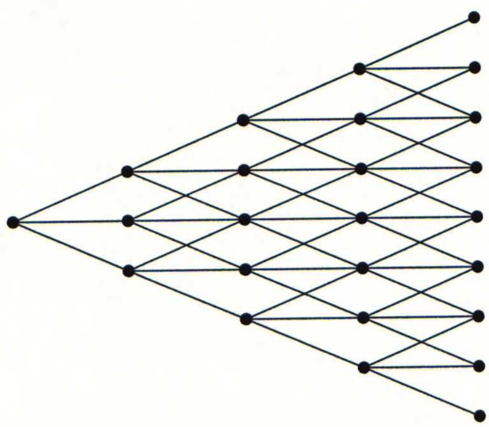


Figure 3-5 Trinomial lattice

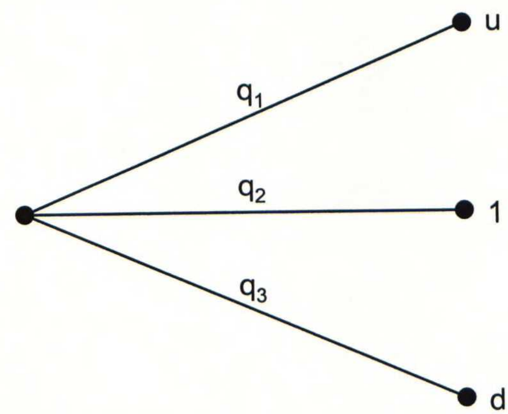


Figure 3-6 Single-period trinomial lattice

The trinomial lattice cannot be used to replace the binomial lattice because it is not possible to replicate three possible outcomes using only the underlying asset and the risk-free asset. However, the trinomial lattice can be used to implement risk-neutral pricing. (Luenberger 1998, p. 366)

Figure 3-6 shows a single-period trinomial lattice. The probabilities q_1, q_2, and q_3 are the risk-neutral probabilities of moving along the arcs. The asset values are u, 1, and d, respectively. By setting $d = 1/u$, upward movement followed by a downward movement is equal to 1.

The parameters can be assigned by arbitrarily selecting a value for u. Then, if the mean value for the step is $1 + r\Delta t$ and the variance is $\sigma^2 \Delta t$, the risk-neutral probabilities can be found by solving the following equations:

$$
\begin{aligned}
&q_1 + q_2 + q_3 = 1 \\
&uq_1 + q_2 + dq_3 = 1 + r\Delta t \\
&u^2 q_1 + q_2 + d^2 q_3 = q^2 \Delta t + (1 + r\Delta t)^2
\end{aligned}
$$

When the probabilities are found, the lattice can be solved backward as in the binomial procedure. The choice of u may require some experimentation because certain values may result in negative values for the probabilities. (Luenberger 1998, p. 367)

Lattice models can be extended even further. For instance, Boyle (1988) and Bollen (1999) have studied pentanomial lattices. Boyle et al. (1989) have even developed an n-dimensional lattice method.

3.6 Parameter Estimation

An important difference between financial and real options is how valuation parameters are estimated. It is relatively easy to estimate the parameters needed in the valuation of financial options because the underlying asset is a traded security. The security price can be observed, and the variance of its rate of return can be estimated from historical data or by calculating the forward-looking implied variance from other options on the same asset (Copeland & Antikarov 2001, p. 111). Whereas parameter estimates for financial options are usually easily available, the estimation of real option parameters is a challenging task. This section explains how the task can be carried out.

Six parameters need to be estimated in real option applications. Four of these parameters – present value of the underlying asset, the risk-free rate, the time to maturity of the real option, and the exercise price – are relatively easy to estimate. According to Davis (1998), the estimation of the last two parameters, the volatility and dividend yield of the underlying asset, cause the most problems. Majd and Pindyck (1987) even comment that "it may be difficult or impossible to estimate them accurately".

In the case of real options, present value of the underlying asset cannot usually be observed from market prices. However, when the future cash flows of a project are known, the cash flows can be discounted to arrive at the present value. The required assumptions are similar to the ones made in traditional NPV calculation (Copeland & Antikarov 2001, p. 111).

It is a common practice to use the yield on Treasury bills as the risk-free rate. Treasury bill, or T-bill, is a short-term debt maturing in less than one year and issued by the U.S. government. The short-term nature of T-bills makes their value insensitive to interest rate fluctuations. Moreover, inflation uncertainty is usually negligible over the course of a few months. (Bodie et al. 1999, p. 31, 181)

Time to maturity is the period for which the opportunity to exercise a real option is valid. It is not fixed as in the case of financial options but can usually be defined with sufficient accuracy when the dynamics of a project are known. Exercise price is the investment cost that is also known in most cases.

Asset price volatility is the most demanding parameter to be estimated. According to Davis (1998), current methods are largely ad hoc, which introduces potential error into the valuation process. In addition, most valuation models assume constant volatility. This assumption may not always be realistic, although Amram and Kulatilaka (1999) present support for it. Moreover, the same simplifying assumption is also often made in other kinds of analyses, such as in commonly used regression analysis (Pindyck & Rubinfeld 1998, p. 58 – 59). It would be possible to take into account a changing volatility but this would require the use of advanced mathematical methods.[11] However, such methods are beyond the scope of this study because they would make a real option model too complicated for most practitioners to use and understand.

The volatility used in the binomial lattice is the standard deviation of the rate of return on the value of the underlying asset (see, e.g., Luenberger 1998, p. 297 – 299, and Copeland & Antikarov 2001, p. 244 – 253). In general, a project's value at time t is PV_0e^{rt}, where PV_0 is the present value at time zero and r is the rate of return. From this relationship it follows that

$$rt = \ln\frac{PV_t}{PV_0}.$$

When $t = 1$, this simple transformation can be used to estimate the project volatility based on the present value of the project at times zero and one. Copeland and Antikarov (2001, p. 244 – 253) use Monte Carlo simulation to compute the present values. They make stochastic models of the assumptions used in calculating the future cash flows of the project. The simulation produces a frequency distribution of the annual rates of return. The volatility can be estimated from this distribution.

The shortcoming of Copeland and Antikarov's simulation approach is that probability distributions have to be given for the underlying assumptions, such as

[11] For instance, ARCH and GARCH models could be used.

prices and costs. In some cases, this may not be easier than giving a probability distribution directly to the present values of the project itself. In addition, estimating probability distributions for all projects can be a very time-consuming task with an unreliable outcome.

Ollila (2000) uses an equity approach to estimate the volatility of a project. In the equity approach, the stock value of the company who owns the project is used. Because this approach is only valid when the project closely reflects the general riskiness of activities of the company, an alternative is to find companies that operate only on the target market of the R&D project. If such comparable companies can be found, the historical annual volatilities for the return on their stock value can be used as a rough estimate for the volatility of the project. In practice, this approach is rarely applicable.

According to Copeland and Antikarov (2001, p. 236), a common mistake is to assume that the volatility of the underlying asset is the same as the volatility of one of its components. For example, the price of gold is not a good proxy for the volatility of a gold mine. The quantity of gold in the mine, the costs of extraction, and interest rates, among others, also affect the volatility of the mine project.

In short, there are no easy methods for estimating the volatility of the underlying asset. Some authors (e.g., Teisberg 1994) calculate several option values using a variety of standard deviations, as they cannot make an exact volatility estimate.

Suitable values for the multiples u and d, which are used to calculate the upside and downside changes of the asset price, can be found when the annual standard deviation σ of the relative change in the asset price is known. For small Δt, the multiples can be approximated as

$$u = e^{\sigma\sqrt{\Delta t}}$$

$$d = e^{-\sigma\sqrt{\Delta t}},$$

where e is the base for natural logarithms, and Δt is the time interval of steps in the lattice. In practice, this approximation is used even when Δt equals one year. (Luenberger 1998, p. 314 – 332)

The final parameter is the dividends that may be paid out to the holders of the underlying asset. For instance, the dividends can be cash flows from a project to its owners. Dividends reduce the present value of the asset, which benefits holders of a put option but reduces the value of a call option on the asset.

Adjusting for dividends generally causes problems in a binomial lattice because the nodes do not recombine unless the dividends are assumed to be proportional to the values in the lattice (Copeland & Antikarov 2001, p. 124 – 125). In this study, the dividends are assumed to be zero.

4 Portfolio Models in R&D Project Selection

There are usually more projects available for selection than can be undertaken within the physical and financial constraints of a company (Archer & Ghasemzadeh 1999, p. 207). A separate evaluation of each R&D project is unlikely to result in the most productive use of a company's limited resources. In fact, it can be argued that a company should view its R&D projects as a portfolio rather than as individual projects.

The first section of this chapter defines basic project concepts. The second section introduces the theory of project portfolio management. As will be shown, project portfolio management is an extensive process, which is closely linked to the strategy of an organization. The third section focuses on portfolio models found in literature, and the fourth section discusses some of the common problems with using these models. The last section considers the use of real options in portfolio models.

4.1 Basic Project Concepts

Terms such as project management, program management, project portfolio management, and portfolio theory are often ambiguously used. This section defines each of these terms so that further discussion can be carried out without misunderstandings on terminology.

According to Gareis and Huemann (2001), a project is a temporary organization for performing a specific process. Projects are typically short- or mid-term undertakings of medium or high complexity. A set of projects, which are associated with each other by common objectives, forms a program. Programs are usually mid- or long-term processes of high complexity.

Gareis and Huemann (2001) define project management as a business process, which starts with the project assignment and ends with the project approval. It consists of several sub-processes, such as project start, project co-ordination, project controlling, project discontinuity management, and project close-down. Correspondingly, program management is a process consisting of similar sub-processes on the program level.

The projects and programs, which are performed by a company at a certain point in time, form a project portfolio (Gareis & Huemann 2001). In other words, a project portfolio consists of projects and programs that are managed under a single management umbrella. The projects and programs may be related or independent of each other but they share the same strategic objectives and the same scarce resources, for which they compete. (Dye & Pennypacker 1999, p. xii)

Figure 4-1 illustrates a project portfolio that is a collection of programs, which – in turn – are collections of projects with common objectives. Projects can be further divided into subprojects. (Aalto 2001)

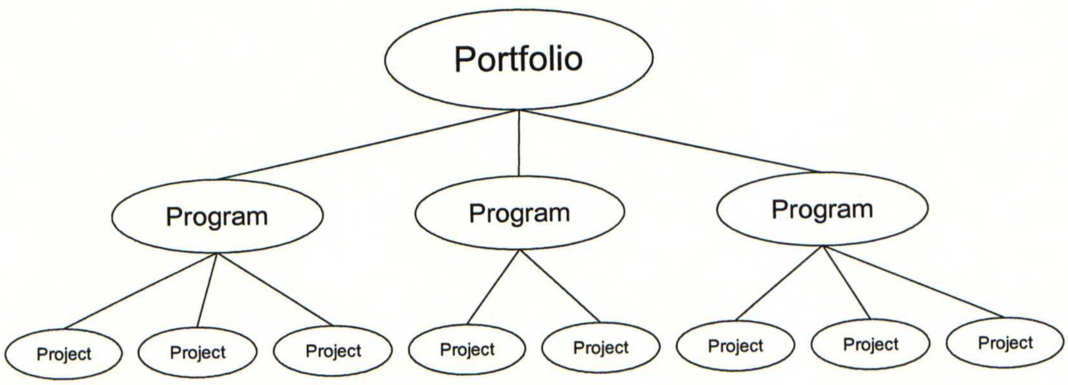


Figure 4-1 Model for organizing project portfolio management (Aalto 2001)

Project portfolio management can be defined broadly or narrowly. According to Turner's (1999, p. 341 – 363) narrow definition, project portfolio management is the process of managing links between projects and assigning priorities for projects which are appropriate to the allocation of resources. Cooper et al. (1998, p. 3) give a broader definition. They define project portfolio management in the R&D context as "a dynamic decision process, whereby a business's list of active new product and R&D projects is constantly updated and revised". In this process, new projects are evaluated, prioritized, and selected; existing projects can be accelerated or closed down; and resources are reallocated to the active projects. What makes the latter definition broader is that the process is seen to encompass a number of decision-making processes from the review of all projects in the portfolio to making decisions on individual projects on an ongoing basis, and developing new product strategies.

Finally, a difference should be made between project portfolio management and portfolio theory. These two concepts are easily confused with each other because they are both also known as portfolio management.[12] According to Bodie et al. (1999, p. 148) portfolio theory involves the determination of the best risk-return opportunities available from feasible investment portfolios and the choice of the best

[12] For instance, Journal of Portfolio Management deals with institutional investment management.

portfolio from the feasible set. Many of the basic ideas of portfolio theory were presented in the seminal paper by Harry Markowitz (Markowitz 1952). The theory is mainly used in portfolios of financial assets although some examples involving capital assets exist (see, e.g., Pike & Neale 1999, p. 268 – 270). However, the portfolio theory is hardly applicable to R&D project selection in practice.

4.2 Project Portfolio Management Objectives and Framework

Project portfolio management is a very broad subject and, thus, mainly beyond the scope of this study. For instance, Cooper et al. (1998) and Artto et al. (2001) provide additional information on the subject. This section explains briefly the possible objectives that project portfolio management can have, and a framework for managing a project portfolio.

Project portfolio management can have many different objectives depending on the organization in which it is applied. Cooper et al. (2000) have identified a number of reasons for using project portfolio management. The objective can be to maximize the return on R&D spending, or to properly allocate scarce resources. Other objectives could be to yield the right balance of projects, or to communicate project priorities within the organization. Moreover, project portfolio management can be used to link project selection and business strategy, to achieve a stronger focus, or to provide greater objectivity in project selection.

According to Roussel et al. (1991, p. 93), the purpose of R&D portfolio planning is typically to reach the optimum point between risk and reward, stability and growth. The definition of optimum may vary between organizations: other companies may seek higher reward through higher risk, while some may trade off growth for stability.

Whatever the objectives of project portfolio management are, the ultimate goal is to implement the company's strategy. According to Aalto (2001), project portfolio management cannot bring value to the company without a sound strategy and a link between the strategy and portfolio management.

Archer and Ghasemzadeh (1999) present a well-known framework that explicitly links strategy with project portfolio management. This framework is shown in Figure 4-2. The major stages are represented by the heavily outlined boxes. Ovals represent pre-process activities, and post-process stages are in the lightly outlined boxes.

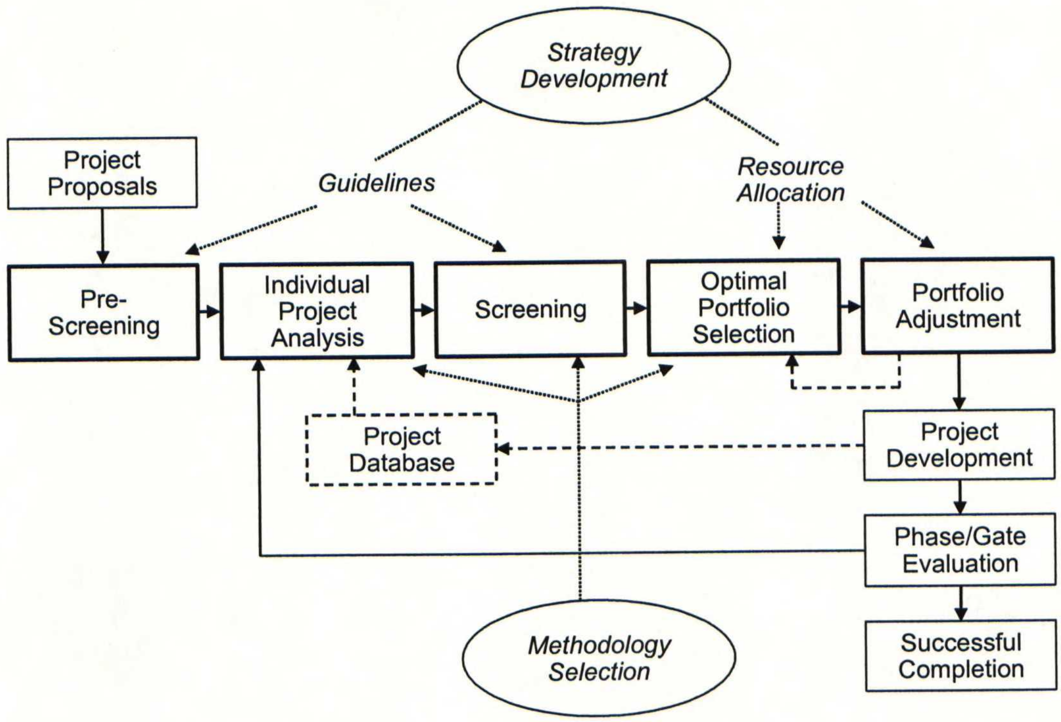


Figure 4-2 Framework for Project Portfolio Management (Archer & Ghasemzadeh 1999)

The end result of the framework is a portfolio that meets the objectives of the organization. Archer and Ghasemzadeh (1999) state that an important aspect to portfolio adjustment is achieving some form of balance among the projects that are selected. This requires displays on certain portfolio dimensions, such as risk, the size of projects, and short-term versus long-term projects. This is where the focus of this study is on. Next section will discuss portfolio models that allow decision-makers to achieve portfolio balance.

4.3 Portfolio Models in Literature

Methods for the selection and management of an R&D project portfolio have attracted wider interest since the late 1950s (Gustafsson & Salo 2001). The early proposed methods were almost entirely based on optimization techniques but since then, many other methods for project and portfolio evaluation have been developed. A classification and short description of these relatively divergent methods was given in Section 2.3. This section focuses on portfolio models, which combine visual charts with several other project selection methods.

A model is a simplification of reality intended to promote understanding. Hence, portfolio models aim to simplify a company's collection of R&D projects in a way that leads to better understanding of the whole. A portfolio is simplified by considering only a limited number of parameters at a time. The parameters, or dimensions, of a portfolio should be selected so that they give the best possible support for the decisions on R&D project selection. According to Bard et al. (1988, p. 140), project selection models should include dimensions that managers feel are the most important, and to which they can provide hard data or, at least, firm opinions.

Traditional dimensions used in portfolios, which focus on business unit or product level, are the attractiveness of the business or product, and the degree of fit with the rest of the portfolio. Attractiveness refers to the profitability and the growth rate of the business or the product, and fit is related to balance and synergies within the portfolio. (Johnson & Scholes 1999, p. 286 – 287)

Figure 4-3 shows some traditional models for analyzing a product portfolio. The models date back to the 1970s. The aim of these models is to determine the extent to which an organization's business units are balanced as a whole. One of the first – and also one of the most famous – is the BCG matrix[13], which classifies business units in relation to market share and market growth. The McKinsey-GE matrix[14] maps businesses based on their competitive position and industry attractiveness, whereas product/market evolution matrix combines competitive position with the stage of product or market evolution. (Johnson & Scholes 1999, p. 186 – 189)

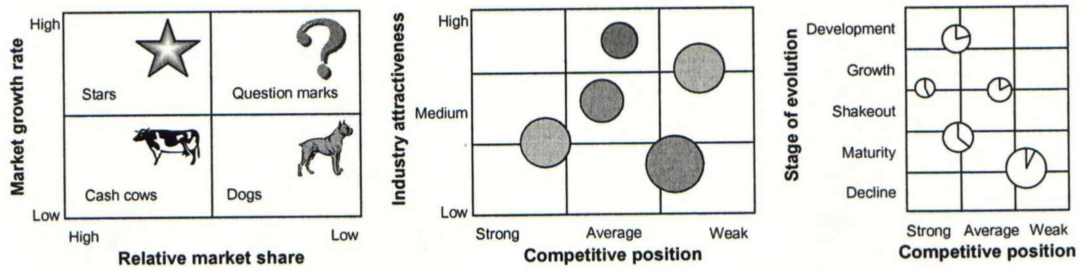


Figure 4-3 Traditional portfolio models: BCG matrix, McKinsey-GE matrix, and product/market evolution matrix

Although the traditional models are commonly used to analyze R&D project portfolios, they have not been developed for that particular use. The models allocate resources across existing products or businesses, whereas the focus of R&D portfolios is mostly on new products and opportunities. Because of this different

13 Named after The Boston Consulting Group, which developed the model.

14 The model was originally developed by McKinsey & Company and General Electric.

focus, the information needs are also different. The information required to analyze R&D projects is more future-oriented and, thus, typically more unreliable. Bearing in mind these differences, the traditional models can still be useful if they are able to support management in making better decisions. (Cooper et al. 1998, p. 9)

Since the traditional models were introduced, numerous other models have been developed. The dimensions used in these models vary significantly. It is next to impossible to suggest a generic list of best dimensions to use as the dimensions should be selected for each organization individually. However, Aalto (2001) provides some examples of dimensions that can be used in finding the right balance:

- Fit with business or company strategy
- Inventive merit and strategic importance to the business
- Durability of the competitive advantage
- Market potential and size
- Market attractiveness
- Reward, based on financial expectations
- Technical and commercial probabilities of success
- Costs to completion
- Time to completion
- Capital and marketing investments required to exploit
- Project maturity
- Competitive impact of technologies
- Technical familiarity

Perhaps the most common type of portfolio models is a risk-reward model. There exists a large variety of these models as both risk and reward can be measured with various metrics. Risk is typically measured as the probability of commercial or technical success, or as the combination of these two. Reward can be estimated qualitatively or quantitatively. According to Cooper et al. (1998, p. 57), some companies prefer to use qualitative measures as they see that "too heavy an emphasis on financial analysis can do serious damage, notably in the early stages of a project."

Figure 4-4 shows two examples of risk-reward models used in practice. The first, used by a division of a major chemical company, uses probability of technical success as the measure for risk and NPV as the measure for reward. The size of each bubble shows the resources to be spent on each project. The model divides the projects into four quadrants. Pearls are projects with a high likelihood of technical success and which are expected to yield high rewards. Oysters are the "long-shots": projects which have a high expected payoff but a low likelihood of technical success. Bread and butter projects are the ones bringing in the steady yet low rewards. Finally, white elephants are projects which are both low-success and low-rewards. The number of white elephants should be kept to minimum. (Cooper et al. 1998, p. 57- 58)

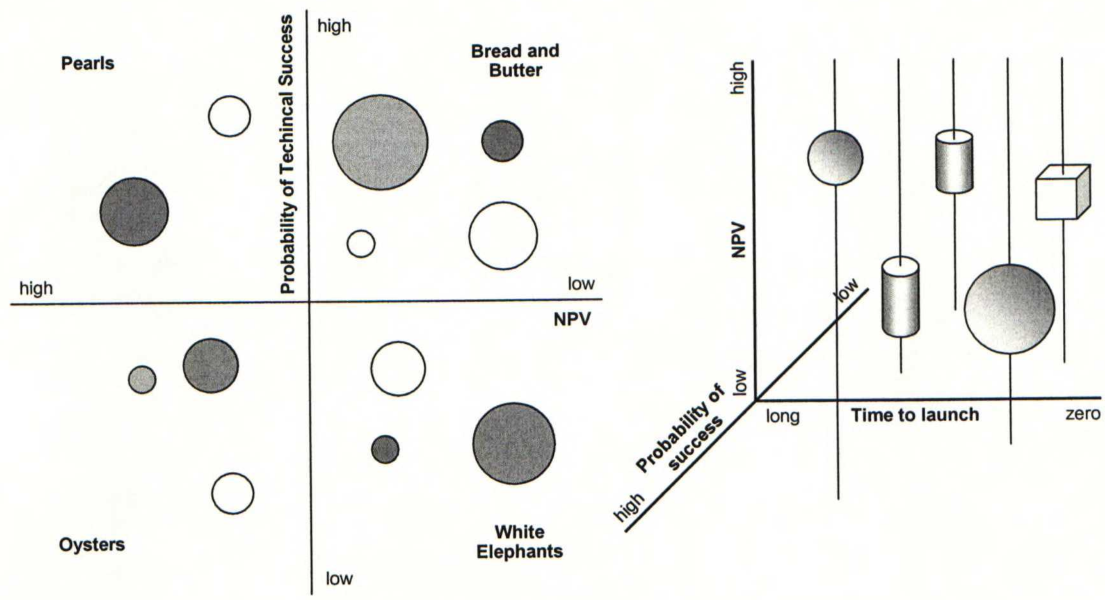


Figure 4-4 Examples of risk-reward models (Cooper et al. 1998)

The other model shown in Figure 4-4 is a multi-dimensional portfolio model used in Procter & Gamble. This example shows how much information can be displayed at one time. In the model, the x-axis (time to market) and the z-axis (probability of success) reflect risk, and the y-axis (NPV) reflects the expected reward. In addition, the shape of the project captures the degree of fit with the company's strengths, and the color of the project shows the roadmapping stage of the project. (Cooper et al. 1998, p. 61 – 62)

As risk is an important dimension in R&D project selection, further discussion on it is justified. Smith and Reinertsen (1998, p. 223) identify two kinds of risk: technical risk and market risk. Technical risk can be defined as the probability of failing to achieve the performance, cost, or schedule targets that have been specified for the R&D project. In other words, it is the risk of poor technical execution. Market risk, on the other hand, is the probability of not meeting the needs of the market, assuming that the specification has been satisfied. It is the risk of selecting the wrong target.

The distinction is useful because of the simultaneous attention to technical and marketing issues. Companies usually place more emphasis on technical risk because it is generally more apparent and easier to manage than market risk. However, Smith and Reinertsen (1998, p. 224) suggest that approximately three-fourths of new-product failures relate to misjudged market, and only a fourth are related to poor technical execution.

Risk is not only a negative matter. Therefore, it should not be minimized but balanced. If a company is unwilling to take risks, it is unlikely that the company will earn above-average returns in the long term. A new project may be highly risky but it may still be worthwhile in balancing a large number of low-risk projects. On the other hand, low-risk projects may be needed to balance projects of higher risk. (Crawford & Di Benedetto 2003, p. 249)

MacMillan and McGrath (2002) present a portfolio model that builds on the technical and market risk. As shown in Figure 4-5, the model can help in allocating different, strategically decided proportions of resources to each type of R&D projects. The types include enhancement and platform launches that are of lower risk, scouting options of high market risk, positioning options of high technical risk, and stepping-stone options, which have simultaneously high marketing and technical risk. The percentages shown in the figure are only illustrative; each company has to decide the right proportions based on its own strategy.

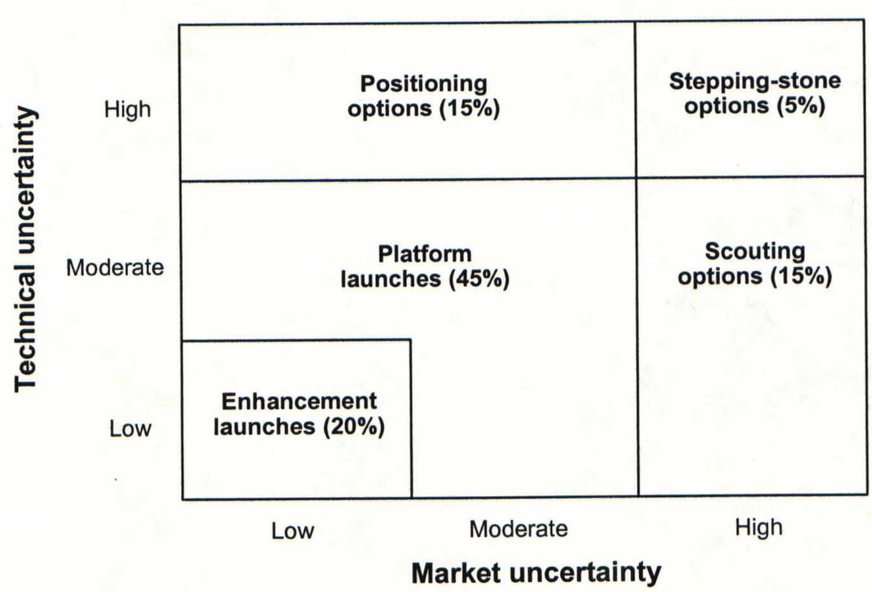


Figure 4-5 R&D portfolio showing the allocation of resources based on technical and market uncertainty (MacMillan & McGrath 2002)

Instead of assessing risk only as being low, moderate, or high, probabilities can also be used. Tritle et al. (2000) provide a numerical range that can be used in assigning probabilities. This range is shown in Figure 4-6.

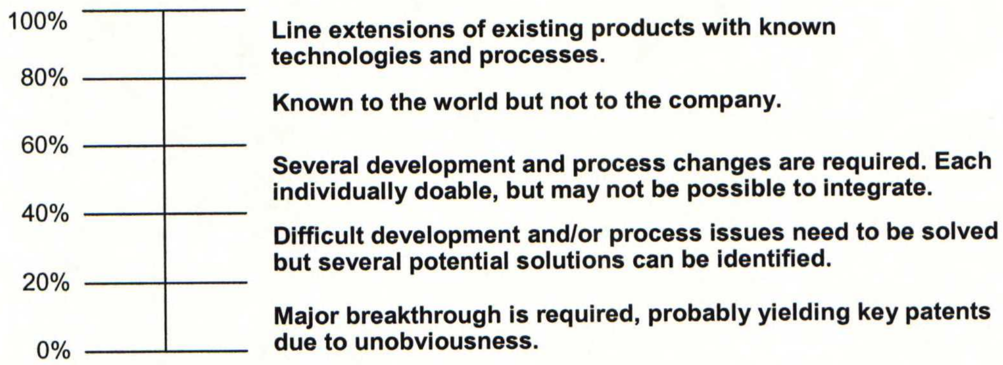


Figure 4-6 Guidelines to assigning probabilities of success (Tritle et al. 2000)

An endless variety of other portfolio models could be drawn based on any logical combination of the relevant dimensions. Moreover, not all portfolio models need to be matrices like the ones presented in this section. Traditional histograms, bar charts, and pie charts may work as well in portraying portfolio balance. However, as ten more portfolio models will be discussed in the next chapter, it is not reasonable to continue presenting various models in this section. Numerous portfolio models that are used in practice can be found in, for example, Cooper et al. (1998).

Portfolio models can be enriched by taking advantage of other planning and analysis methods. These include, for instance, sensitivity analysis and scenario planning. The methods can provide additional insights into portfolio analysis as illustrated in Figure 4-7. The figure shows low, base, and high scenarios for a project portfolio. The analysis reveals how sensitive the portfolio's balance is to changes in the underlying assumptions.

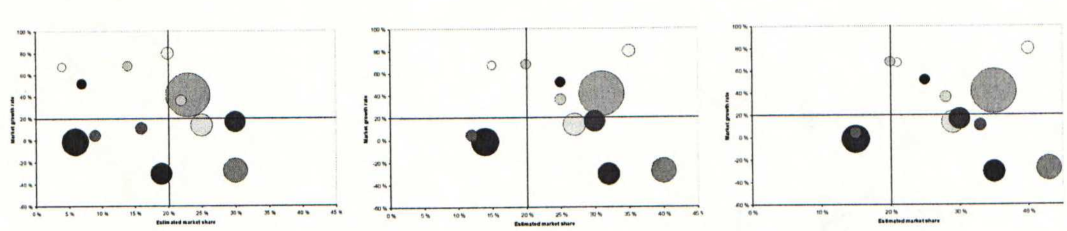


Figure 4-7 Low, base, and, high scenarios illustrated in a portfolio model

Sensitivity analysis examines the effects of a change in one variable, ceteris paribus. According to Schoemaker (1995), a problem with sensitivity analysis is that a large change in one variable is likely to cause changes also in other variables, rendering the ceteris paribus assumption invalid. Scenario planning, on the other hand, changes several variables at a time. Scenario planning attempts to capture the range of possible outcomes and to stimulate decision makers to consider changes to the prevailing mind-set and assumptions. In addition, the possible outcomes are organized into a limited number of scenarios, which are easier to understand and use than the great number of all outcomes.

4.4 Common Problems with Portfolio Models

In addition to collecting a large amount of portfolio models used in practice, Cooper et al. (1998, p. 80 – 81) have identified five main problems in achieving a balanced portfolio through portfolio models. First, many models rely on substantial financial and other quantitative data. This data are often unreliable or perhaps not available at all. Second, there is the problem of information overload. Although it is advisable to use several portfolio models to see the situation from different angles, not every possible model should be used. If everything is mapped against everything, valuable information will be lost.

Third, portfolio models are information displays, not decision models per se. In other words, the models support decisions but do not make them. Managers need to translate the information given by the models to actionable decisions. Fourth, it is not always known how the portfolio models are to be used in an organization. The portfolio models need to be integrated into the capital investment process so that they play a role in the real decision-making situations.

Finally, if a company is unable to transform its strategy into the right balance of projects, the portfolio models are of limited use. The managers need to know whether the balance is right or wrong in order to be able to make portfolio decisions.

Taking all these problems into consideration, Cooper et al. (1998, p. 81) conclude that portfolio models can be effective tools, but only if the choice of models is carefully thought out. Models should be tested before actual use, and only relevant models should be used.

4.5 Real Options and Portfolio Models

The portfolio models presented so far have not taken advantage of the real option theory presented in Chapter 3. As has been argued, real options offer additional insights into the valuation of R&D projects. Therefore, including the real option values of projects into portfolio analysis is an interesting opportunity to improve the analysis. This section discusses how real options can be used in portfolio models.

As was discussed in section 3.4, the true NPV of a project can be considered to consist of the NPV of the basic project and the real option values embedded in the project. Consequently, a straightforward way to include real option values into portfolio models is by using true NPV instead of basic NPV as the measure for reward. Another approach is to use real option value as a dimension of its own.

However, there is a problem in including real option values of projects into portfolio models. According to Laamanen (2002, p. 83), a company typically has a limited capacity to exercise options. The capacity constraints can include the time needed to raise funds, the amount of available funding, and the personnel needed to work on investment opportunities. As a consequence of these constraints, it is not reasonable to assume that all real options can be exercised. Especially if the real option values used in a model include values from growth options, the sum of individual growth options provides a highly optimistic total value making also the model look too optimistic.

Luehrman (1998b) presents one of the few approaches in literature to incorporate real options and portfolio models. The option space shown in Figure 4-8 consists of two dimensions, both of which measure a different part of the value associated with the flexibility to defer an investment. These two dimensions are value-to-cost ratio and volatility.

Value-to-cost is defined as the ratio of the present value of the underlying asset, S, to the present value of the exercise price, $PV(X)$:

$$\text{value-to-cost} = \frac{S}{PV(X)}.$$

Essentially, value-to-cost ratio contains the same information as the normal NPV. However, it adds the time value of being able to defer an investment. When the investment can no longer be deferred, NPV and value-to-cost ratio support identical decisions. In this case, when NPV is positive, value-to-cost is greater than one; and when NPV is negative, value-to-cost is less than one. On the other hand, if there is still some time left to expiration, value-to-cost ratio may support different decisions because it explicitly includes interest earned while waiting. This means that value-to-cost can give a value greater than one, which implies a decision supporting the investment, even though its conventional NPV is negative. (Luehrman 1998a)

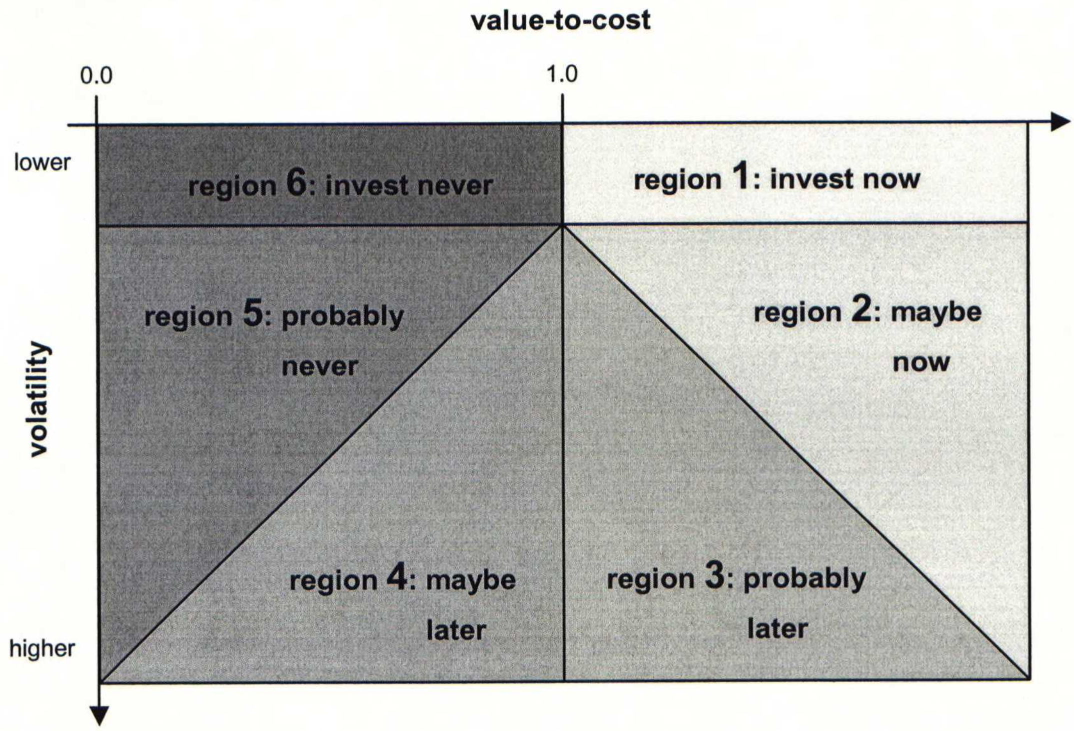


Figure 4-8 Option space defined by value-to-cost and volatility (Luehrman 1998b)

The second dimension, volatility, measures how much circumstances can change before the option expires. Luehrman (1998a) measures volatility with cumulative standard deviation. In other words,

$$\text{volatility} = \sigma\sqrt{t}\,,$$

where σ is the standard deviation per period in project returns, and t is the number of periods.

The option space can be divided into regions as seen in Figure 4-8. Value-to-cost ratio of one divides the space into two sides, which both contain three regions. The projects whose value-to-cost is greater than one and which correspondingly lie on the right side of the space are promising because the underlying assets are worth more than the present value of the required investment. In contrast, the projects on the left side are less promising because the underlying assets are worth less than the present value of the required investment.

If volatility is close to zero, as in regions 1 and 6, the division between the right side and the left side is decisive: in region 1, the value-to-cost is greater than one and therefore the investment should be made now; in region 6, the value-to-cost is less than one and the investment should never be made. This is because only minor, if any, changes are expected in the value of the project due to the low volatility.

As already explained, the value of a call option increases not only when value-to-cost ratio increases but also when volatility becomes higher. This warrants the division of the option space into more than just two regions. On the right side of the space, there are two additional regions, namely regions 2 and 3. Projects in region 2 have a positive NPV if exercised immediately, whereas projects in region 3 have a negative NPV. In other words, region 2 is in the money and region 3 is out of the money.[15]

Projects in regions 2 and 3 have time left to expiration because cumulative volatility is positive. In region 2, early exercise should be considered because NPV of immediate exercise is positive. However, by investing now the company loses the advantages of waiting and, therefore, a comparison of the value of investing immediately with the value of waiting should be made to decide if it is better to invest now or later. In region 3, early exercise is not advisable because of the negative NPV. However, because the value-to-cost ratio is positive, most projects in the region are likely to become worthwhile investment opportunities later on. (Luehrman 1998b)

In addition to region 6, two other regions can be identified on the left side of the option space. Projects in region 4 may become attractive investments later on because of the high volatility that could result in an increase in the project's value. For projects in region 5 this is unlikely, as volatility is lower. Investment will probably never take place.

[15] The line, or curve, that separates these regions is correspondingly at the money.

5 Development of R&D Project Selection in Practice

This chapter turns theory into practice. Real option valuation and portfolio models discussed in the previous two chapters are applied to R&D projects of the case company, which provides an opportunity to test their usefulness in practice. The first section describes the objectives set for the development of R&D project selection in the case company. The second introduces briefly the organization in which the models are used. The third section presents a real option model for the evaluation of individual R&D projects, and the fourth section analyzes ten portfolio models in the case company setting.

The case company operates in several high-technology sectors and invests heavily in R&D on both completely new and existing products. The R&D projects analyzed in this study include projects that have passed the early stages of ideation and opportunity evaluation. In other words, the projects are already existing, have been found to fit the company's strategy, and at least some information – such as financial forecasts – is available. Many projects are already selling to the market, and some even in high volumes.

This study does not describe the case company or its practices in detail, as any information concerning the actual R&D investment process, project portfolio, or individual projects is very sensitive in nature. All information presented in this chapter is fictitious. The information is used purely to illustrate the methods that were developed in the case company. Nothing in this chapter presents the actual situation or business of the case company or any of its R&D projects.

5.1 Development Objectives

The following two objectives were set for improving R&D project selection in the case company. First, the management was interested in a new analytical method to complement the methods traditionally used in the evaluation of individual R&D projects. The methods that have been used include a wide range of financial methods such as net present value, internal rate of return, and time to profit, as well as several more qualitative methods. However, as has been discussed, traditional financial methods often fail in giving a realistic valuation of a project in a highly uncertain technological and market environment. To better capture the dynamics of the industry, a real option model was selected as the complementary method.

Second, the management was interested in improving the models used in balancing the portfolio of R&D projects. The goal was to find new ways of looking at the issue of balance, and also to analyze some of the existing models. The allocation of R&D investments was of particular interest.

The strategic fit of projects was left out of the explicit scope of this study. Measuring strategic fit would have required a thorough analysis of the case company's strategy. This kind of analysis could not be made public. In addition, strategy is reflected in the targets and the optimal balance of the portfolio. This is the reason why this chapter does not discuss explicit targets or the optimal balance of the portfolio models.

A leading idea in the development was to create models that would be relatively simple and easy to understand. There is evidence (e.g., Honko et al. 1982, p. 132) that in most cases it is possible to use only relatively simple models in practical decision-making. Moreover, as the real option model developed in this study was an initial attempt to explicitly value the real options in R&D projects of the case company, the model had to be simple in order to be understood and accepted.

5.2 R&D Management Organization

This section introduces briefly the general environment in which the models that will be presented are used. As has been explained, the development of the whole investment process was not in scope of this study. In addition, for confidentiality reasons, the organization and process is introduced only on a very rough level. However, general comprehension of the underlying process helps to understand the models itself.

Figure 5-1 shows a simplified version of the business and R&D steering organization. Business steering process is responsible for creating and implementing the overall strategy of the company, whereas R&D steering process concentrates on technology strategy. Both processes cover three organizational levels: divisional level, business unit level, and program/project level.

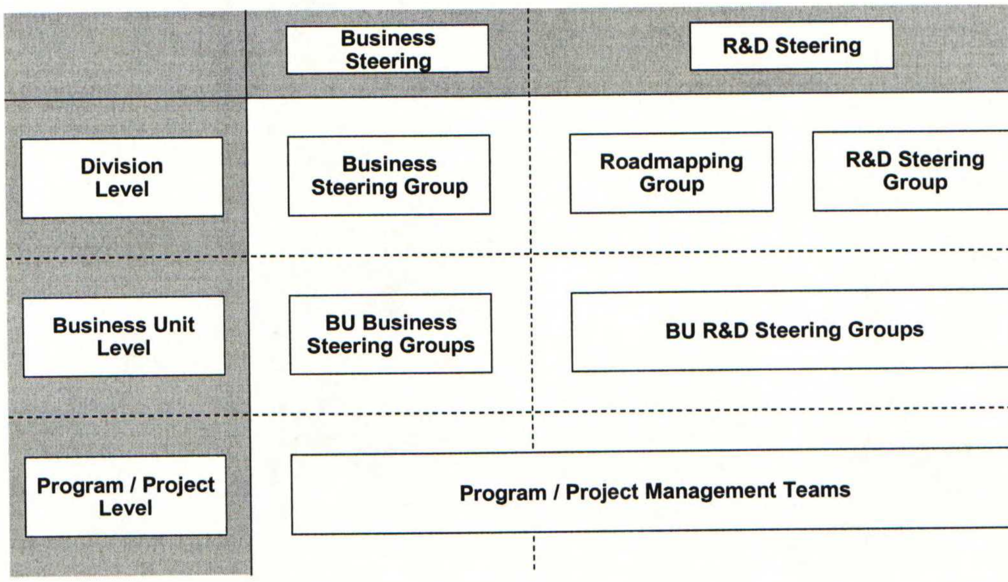


Figure 5-1 Business and R&D steering organization

The highest authority in the division's business steering process is the Business Steering Group. The group members include the manager in charge of the division, and the heads of business and support units[16] of the division. Each business unit has also its own business steering group consisting of, respectively, the head of the business unit, and the program and project managers belonging to that group. Business unit level steering groups are responsible for the creation and implementation of strategy within business units.

There are two groups operating on the divisional level in the R&D steering process. The Roadmapping Group consists mainly of the same members as the Business Steering Group. It is responsible for the strategic side of the R&D steering process. The other group, the R&D Steering Group, concentrates on the operational side of the R&D steering process.

The portfolio models developed in this study are used in the roadmapping and steering groups on the divisional level when analyzing the portfolio of programs and projects. In addition, business unit level steering groups in large business units can analyze their own portfolios with the models. However, care needs be taken so that no sub-optimization takes place within the business units. The optimization of the portfolio needs to take place on the divisional level. The real option model, which is

[16] Support units include, for example, strategy and business development, and business control.

presented in the next section, can be used on any organizational level to value real options in individual R&D projects.

In an interview, Professor Artto highlighted the importance of the group meetings to the use of the models. The models have to be explicitly included in the agenda of the meetings so that they will have an impact on the decision-making.

5.3 Real Option Valuation of Staged R&D Investments

This section presents a real option model that can be applied in the valuation of staged investments, which are typical to all R&D-intensive industries in general (Trigeorgis 1998, p. 11) and the R&D projects of the case company in particular. In a staged investment, the required investment is not incurred as a single up-front outlay but as a series of outlays over time. Each stage can be viewed as a call option on the value of subsequent stages. The staged investment creates the option to abandon the project at any given stage.

The model is partially based on the literature presented in Chapter 3 and partially based on development work in practice. The development was an iterative process in which feedback was received both from the case company and some interviewed academics.

In order to help the reader to understand the model, all the calculations will be presented through an example. The project that is used as the example is a hypothetical, yet representative, R&D project. Table 5-1 shows the staged R&D investments over time and the estimated other cash flows of the project. The investments for the following years are assumed to be constant. For the other cash flows, three scenarios – base, low, and high – are given. The residual value is the present value of future investments or other cash flows at time four.

Table 5-1 R&D investments and other cash flows of an R&D project

	t = 0	t = 1	t = 2	t = 3	t = 4	Residual value
R&D investment	200	300	450	500	450	1100
Other cash flows, base scenario	-	20	400	800	900	1500
Other cash flows, low scenario	-	-5	100	400	600	1100
Other cash flows, high scenario	-	50	500	900	1050	1800

The first task is to build a binomial lattice for the present value of the project's cash flows. If we assume that the cost of capital is 10% and that at time zero the project is proceeding according to the base scenario, the present value of the project's cash flows excluding the R&D investments is

$$PV_0 = \frac{20}{1.1} + \frac{400}{1.1^2} + \frac{800}{1.1^3} + \frac{900 + 1500}{1.1^4} = 2589\,.$$

This value will be used in the first node of the lattice. In order to get the values for the other nodes, the volatility of the project's value is needed. As was discussed in Section 3.6, the estimation of the volatility is a difficult task and often based on ad hoc methods. Monte Carlo simulation of cash flows (see, e.g., Copeland & Antikarov 2001, p. 244 – 269) would have been a good approach but, unfortunately, only the three aforementioned scenarios were readily available.

A realistic simulation requires that some kinds of probability distributions are defined for the parameters, such as product price and costs, used in calculating the cash flows. In practice, it was not possible to create such realistic simulations for all the projects in the case company's portfolio. Therefore, a simpler method for approximating the volatility was devised.

According to an interviewed manager, the scenarios can be interpreted so that there is roughly a 20 percent probability that the cash flows will be below the low scenario, and also the same probability that they will be above the high scenario. In addition, as the base scenario is the best estimate, or guess, for the future, the probability distribution peaks at this scenario.

Figure 5-2 illustrates what the probability distribution of the cash flows could look like and how the scenarios are related to the distribution. The distribution is usually asymmetric, as became evident when analyzing R&D projects of the case company. This is a problem for the binomial lattice, because the lattice approach assumes that the value of the project's cash flows is log-normally distributed.

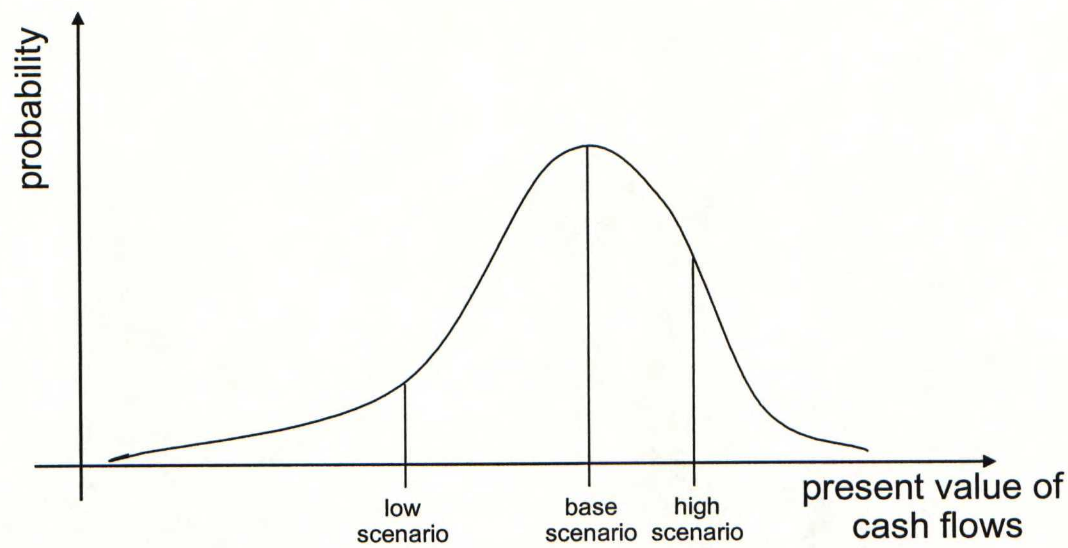


Figure 5-2 Probability distribution of cash flows

To be able to use a simple binomial approach and to make a rough estimate for the volatility, the probability distribution is approximated with a normal distribution. If the low and high scenarios are fixed at the cumulative probabilities of 20% and 80%, respectively, then the mean of the normal distribution must lie exactly in the middle of these two scenarios.

As was explained in Section 3.6, the volatility, which is used in the binomial lattice, is the standard deviation of the rate of return of the project's value. For $t = 1$, the annual rate of return is

$$r = \ln \frac{PV_1}{PV_0} .$$

The volatility can be estimated if the rate of return is calculated for both the low and high scenarios. For the low scenario

$$PV_1 = -5 + \frac{100}{1.1} + \frac{400}{1.1^2} + \frac{600 + 1100}{1.1^3} = 1694 ,$$

and for the high scenario

$$PV_1 = 50 + \frac{500}{1.1} + \frac{900}{1.1^2} + \frac{1050 + 1800}{1.1^3} = 3390.$$

The respective rates of return are

$$r_{low} = \ln \frac{PV_1}{PV_0} = \ln \frac{1694}{2589} = -0.424 \text{, and}$$

$$r_{high} = \ln\frac{PV_1}{PV_0} = \ln\frac{3390}{2589} = 0.269\,.$$

Based on the assumption of normal distribution, the mean lies at

$$r_{mean} = \frac{r_{low} + r_{high}}{2} = \frac{-0.424 + 0.269}{2} = -0.0775.$$

Compared to r_{base} of 0.0953, which can be computed similarly to other returns, the mean is somewhat lower. This means that the estimate for the standard deviation will be somewhat biased, and that the binomial lattice does not perfectly model the dynamics of the real project value. However, as we want to keep things simple and use the normal distribution, this is unavoidable. Moreover, a sensitivity analysis will be done in order to see the real option value when other estimates for the standard deviation are used.

The standard deviation can be calculated by using the standardization theorem (see, e.g., Milton & Arnold 1995, p. 118). Because r_{high} is normal with mean r_{mean} and standard deviation σ, the variable

$$\frac{r_{high} - r_{mean}}{\sigma}$$

is standard normal. Moreover, as the cumulative probability of r_{high} is known to be 80%, which in the standard normal distribution is at $z = 0.8416$, the standard deviation is

$$\sigma = \frac{r_{high} - r_{mean}}{0.8416} = 0.412.$$

Now, as the present value of the project's cash flows and the volatility of the percent changes in the value are known, the binomial lattice can be built. Because we assume that R&D investments are committed once a year, it is logical to use one year as the time span between nodes in the three. Consequently,

$$u = e^{\sigma\sqrt{t}} = e^{\sigma} = e^{0.412} = 1.510\text{, and}$$

$$d = 1/u = 0.662\,.$$

The values of the underlying project are shown in Table 5-2. We assume that no dividends are paid during the first five years of the project to keep the binomial lattice recombining. As an example, the values at time two are calculated as

$$PV_0 \cdot u^2 = 2589 \cdot 1.510^2 = 5904$$
$$PV_0 \cdot ud = 2589 \cdot 1.510 \cdot 0.662 = 2589$$
$$PV_0 \cdot d^2 = 2589 \cdot 0.662^2 = 1135$$

Table 5-2 Binomial lattice for the value of the underlying project's cash flows

t = 0	t = 1	T = 2	t = 3	t = 4
				13463
			8916	
		5904		5904
	3910		3910	
2589		2589		2589
	1714		1714	
		1135		1135
			752	
				498

The sequential compound options are valued backwards, from right to left, because the value of each option is not directly dependent on the value of the underlying project, but on the value to invest at the next stage. Each option is a call option that can be exercised at the cost of R&D investment or left unexercised to abandon the project.

For $t = 4$, the option values are

$$\max(PV_4 - INV_4, 0),$$

where PV_4 is the value obtained from Table 5-2 and INV_4 is the investment outlay at time four. In this case, as there is no flexibility after this point, the investment is the sum of the investment at that time and the residual investment value. Therefore, the option values at time four are

$$C_{uuuu} = \max(13463 - 1550, 0) = 11913$$
$$C_{uuud} = \max(5904 - 1550, 0) = 4354$$
$$C_{uudd} = \max(2589 - 1550, 0) = 1039$$
$$C_{uddd} = \max(1135 - 1550, 0) = 0$$
$$C_{dddd} = \max(498 - 1550, 0) = 0$$

In the last two nodes the option is left unexercised and the project is abandoned.

Risk-free interest rate and risk-neutral probabilities are needed in order to calculate the option values for the preceding stages. The annual yield on 3-month Treasury bills is used to approximate the risk-free interest rate. At the time of writing, the interest rate was 1.20 %.[17] Hence, the risk neutral probability of an upward movement is

$$q = \frac{R-d}{u-d} = \frac{1.012-0.662}{1.510-0.662} = 0.413.$$

The values of call options on the next stage of the investment at $t = 3$ are

$$C_{uuu} = \max\left(\frac{qC_{uuuu} + (1-q)C_{uuud}}{R} - INV_3, 0\right) = 6884$$
$$C_{uud} = \max\left(\frac{qC_{uuud} + (1-q)C_{uudd}}{R} - INV_3, 0\right) = 1878$$
$$C_{udd} = \max\left(\frac{qC_{uudd} + (1-q)C_{uddd}}{R} - INV_3, 0\right) = 0$$
$$C_{ddd} = \max\left(\frac{qC_{uddd} + (1-q)C_{dddd}}{R} - INV_3, 0\right) = 0$$

Here, $INV_3 = 500$. The other preceding stages can be computed similarly. Table 5-3 summarizes the call option values at each node. According to this calculation, the present value of the first option on the staged investment is 325. The values of the later options will depend on how the cash flows will evolve.

Table 5-3 Call option values of the staged investment

t = 0	t = 1	t = 2	t = 3	t = 4
				11913
			6884	
		3446		4354
	1288		1878	
325		316		1039
	0		0	
		0		0
			0	
				0

Finally, Table 5-4 presents a sensitivity analysis for the real option value. As can be seen, the value is quite sensitive to changes in the standard deviation. Therefore,

[17] Source: Federal Reserve Statistical Release H.15, November 12, 2002. <http://www.federalreserve.gov/releases/H15/>

when comparing R&D projects, it may be useful to consider the results of the sensitivity analysis and not just a single estimate for the real option value.

Table 5-4 Sensitivity of the real option value to changes in volatility

$\sigma = 0.30$	$\sigma = 0.35$	$\sigma = 0.40$	$\sigma = 0.412$	$\Sigma = 0.45$	$\sigma = 0.50$
152	230	307	325	382	457

In conclusion, this section presented the real option valuation of staged R&D investments through an example. Rigorous mathematical presentation was avoided in order to make the presentation easy to understand. However, this does not limit the usefulness of the method. Other staged investment projects can be similarly valued by following the procedure demonstrated in this section.

5.4 Portfolio Models in Practical R&D Selection

This section discusses the development of portfolio models in practice. The section starts by giving a brief description on how the research was carried out in the case company. The rest of the section is devoted to presenting ten portfolio models that were tested in the case company.

The development of portfolio models was based on literature, models that were already in use in the case company, and innovation. As with the real option model, the process was iterative. Regular feedback was used to develop the models to meet the needs of the case company as well as possible.

Ten of the most promising models were selected for further analysis. Two of these models, namely models 1 and 5, included variations (1a – 1d, and 5a – 5b), which were analyzed separately. The practical usefulness of the models was evaluated by interviewing seven people in the case company. The interviewed people were:

- Business Analyst
- Senior Manager, Business Modeling
- Head of Business Development
- Director, Business Operations & Control
- Director, Roadmapping
- Head of Business Analysis
- Vice President and General Manager, System & Business Development

The general term manager will be used from now on to refer to all the interviewees.

The interviews lasted typically several hours. The models were discussed one at a time, and the managers were asked to give comments on the models. The opinions of the managers were also quantified by asking three specific questions:

- How easy is the model to understand?
- How relevant are the measures used in the model?
- How reliable are the measures used in the model?

In addition, the managers gave an overall grade for each model. The answer range was from 1 to 5, where 1 was "strongly disagree"/"very bad", and 5 was "strongly agree"/"excellent". The managers were also given the choice to answer "don't know", although no one used this option. At the end of each interview, the managers were asked to select the best three models to be used in practice out of the ten models that were presented.

Next, the models will be discussed one at a time. The text is based on the findings made during the development of the models, and on the interviews. An imaginary, yet representative project portfolio was created in order to provide the necessary input for the portfolio models. The project portfolio is the same in all of the models that are presented in this section, although not all projects are necessary shown in each model.

Models 1a – 1d

Model 1 is three-dimensional. The horizontal axis, or x-axis, is project maturity, and the vertical axis, or y-axis, is expected reward potential. The size of each bubble adds the third dimension into the model. It reflects the size of the R&D investments on each project during the five-year forecasting period. Because there are different measures for both project maturity and expected reward potential, four variations of this model (Models 1a – 1d) were analyzed in the interviews. Two of these, Models 1a and 1b, are shown in Figure 5-3 and Figure 5-4, respectively. Models 1c and 1d are not shown, as they are similar to the first two, with the exception of that they use a different measure for reward.

The initial idea was to use the life cycle phase of a project as the measure of project maturity. However, this idea was soon abandoned as it became evident that different managers may have different opinions on the stage in which a particular project is.

Therefore, two alternative measures for project maturity were taken into use: time to profit and project milestone.

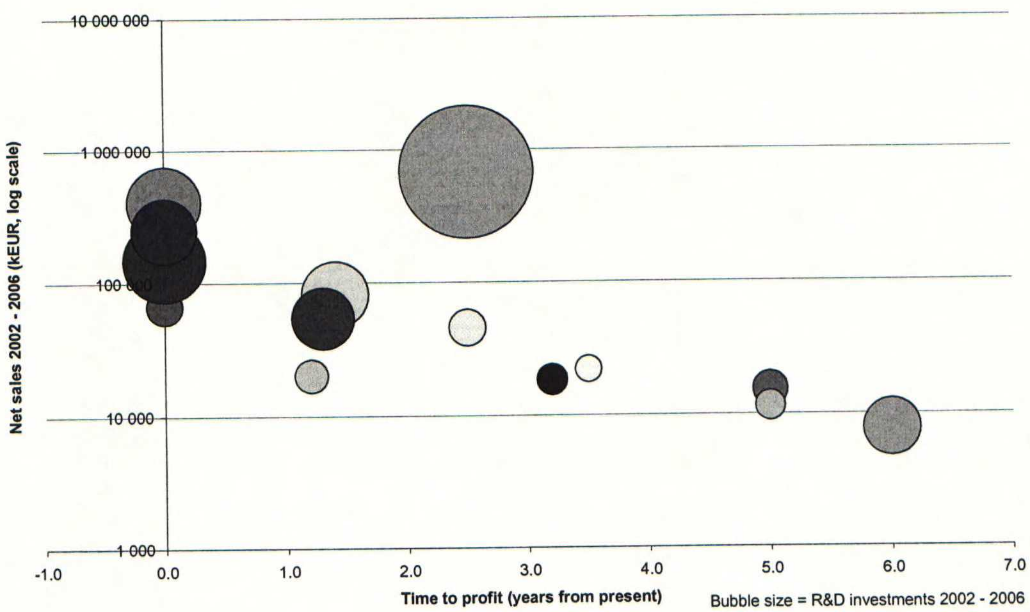


Figure 5-3 Project model showing projects' forecasted net sales and time to profit (Model 1a)

Time to profit, measured from present time, is used in Models 1a and 1c. Some managers considered it problematic that there are several alternative ways to calculate time to profit. However, when the measure is exactly defined, this problem can be avoided.

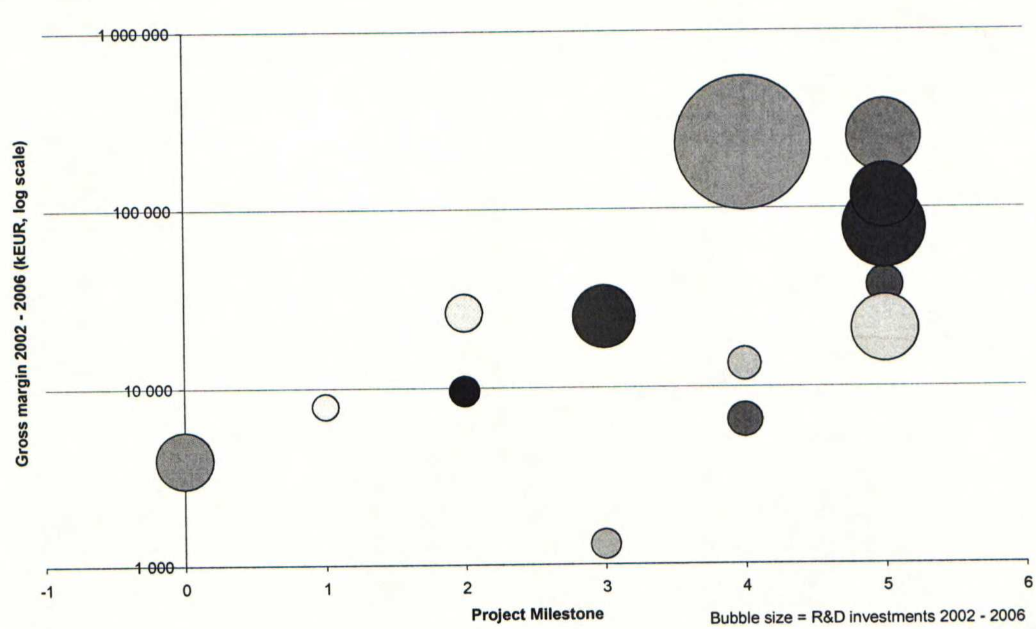


Figure 5-4 Portfolio model showing projects' gross margin and milestones (Model 1b)

Project milestone is used in Models 1b and 1d. Milestones represent significant events in a project's progress. For example, a milestone can signify the completion of the design phase, or the start of product launch. The case company had a pre-defined set of project milestones. These milestones were a natural selection to be used in the portfolio models. As the milestones are numbered upward from zero, the order of projects on the horizontal dimension is roughly the opposite compared to time to profit, which is zero for mature projects.

Two problems with using milestones were identified in the interviews. First, if programs are analyzed, maturity becomes unreliable as different projects inside a program can be at completely different milestone stages. Second, different kinds of projects may progress through milestones slower or faster. The measure is unable to take this into account.

Many possible measures for expected reward potential were considered. Figure 5-5 shows five measures, which were estimated or calculated for each project. Market size was found problematic because, as noted by one manager, it is often more difficult to estimate the total market size than it is to estimate the company's own sales. In the high technology sectors, in which the company operates, it can be difficult to define the market exactly. For example, it is not always clear whether the whole market should be used or only the technological, customer, and geographical segments in which the company operates. In addition, a new product can be a part of a larger system, and therefore it may not have a market of its own.

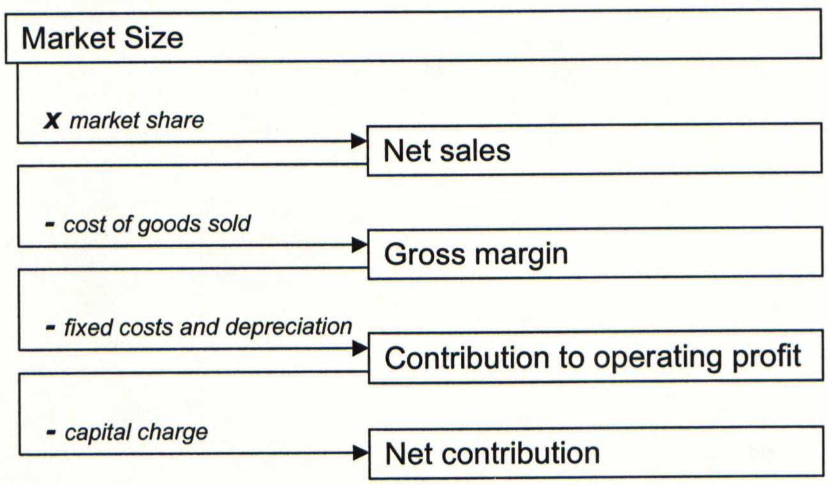


Figure 5-5 Proxies for potential reward based on market estimates and accounting numbers

Model 1a uses net sales, Model 1b gross margin, and Model 1c contribution to operating profit as the measure of expected reward potential. Basic NPV was selected as the measure for Model 1d. A logarithmic scale is often needed to show the reward axis informatively because the project sizes are typically of different magnitudes.

The selection of reward measures for Model 1 is consistent with literature. For example, Rosenau (1996) supports the use of simple estimates of sales, profits, and development expenses. A discounted cash flow analysis at early stages of R&D is often a waste of time since the numbers are wild guesses that are prone to exaggeration.

The interviews showed that although NPV is often considered to be a superior measure for a project's value, it is not a very reliable measure in practice. Net sales and gross margin were considered to be more reliable. In addition, NPV was seen as the least relevant measure for reward. However, no measure was clearly preferred to others.

One manager criticized the model for being too static. However, in general, Model 1 received good feedback in the interviews. This was reflected in the overall grades, in which Models 1a and Model 1c tied for the third place, while Model 1d was ranked the sixth and Model 1b the eighth among all the portfolio models. Although the variations were given different grades, the managers agreed that several variations should be used at the same time in order to get a many-sided view to the portfolio.

As an alternative to showing only the R&D investments, one manager would have liked to see also the total investments including, for example, marketing investments.

Model 2

Model 2 is a traditional histogram. The aim of the model is to sum together all projects in a relatively similar stage of project maturity. Based on this, the model offers an overview of the allocation of R&D investments on projects as seen in Figure 5-6. Possible gaps or unbalance can be identified and analyzed further using other, more detailed models.

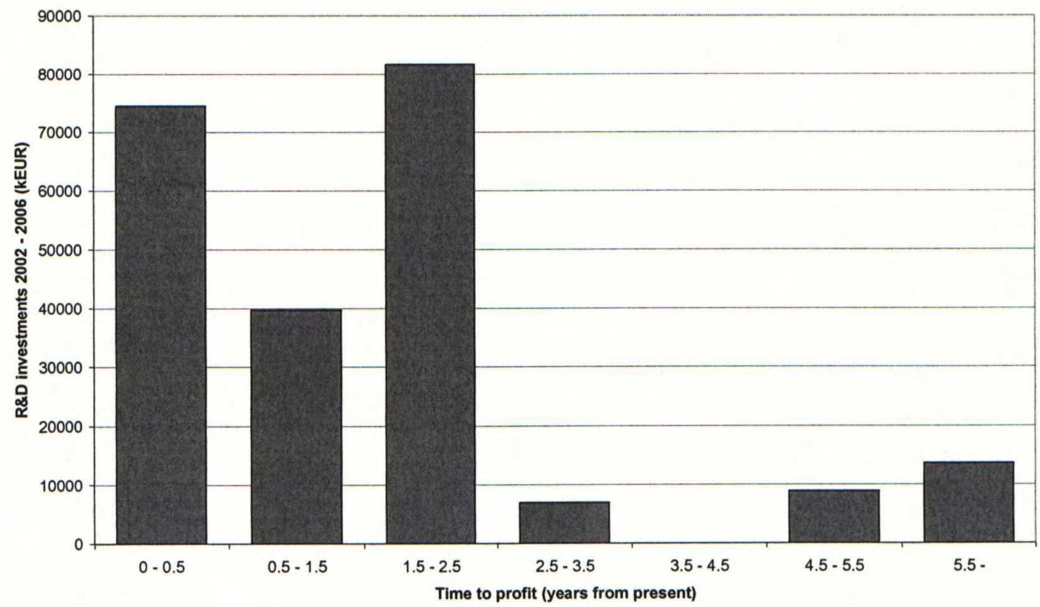


Figure 5-6 Allocation of R&D investments based on projects' time to profit (Model 2)

The model was successful in the sense that it was graded the easiest to understand, and it also received the highest overall grade together with Model 3. On the other hand, the model received negative feedback because it does not directly support the selection of individual R&D projects.

One manager suggested an alternative model, in which R&D investments would be replaced with operating profit. Also, instead of time to profit allocation, the projects could be grouped based on, for example, strategic project streams.

Model 3

Model 3, shown in Figure 5-7, is based on the traditional BCG matrix, which was shortly described in Section 4.3. In this version, the bubble size reflects the relative size of R&D investments like in Model 1. The vertical axis is the market growth rate, and the horizontal axis is the market share.

Two charts were presented to the interviewed managers: the first showing the present situation and the second showing the situation at the end of the forecasting period. One manager said that the latter graph should only be used for speculation and not in real decision-making, as it is based only on very unreliable assumptions of the future.

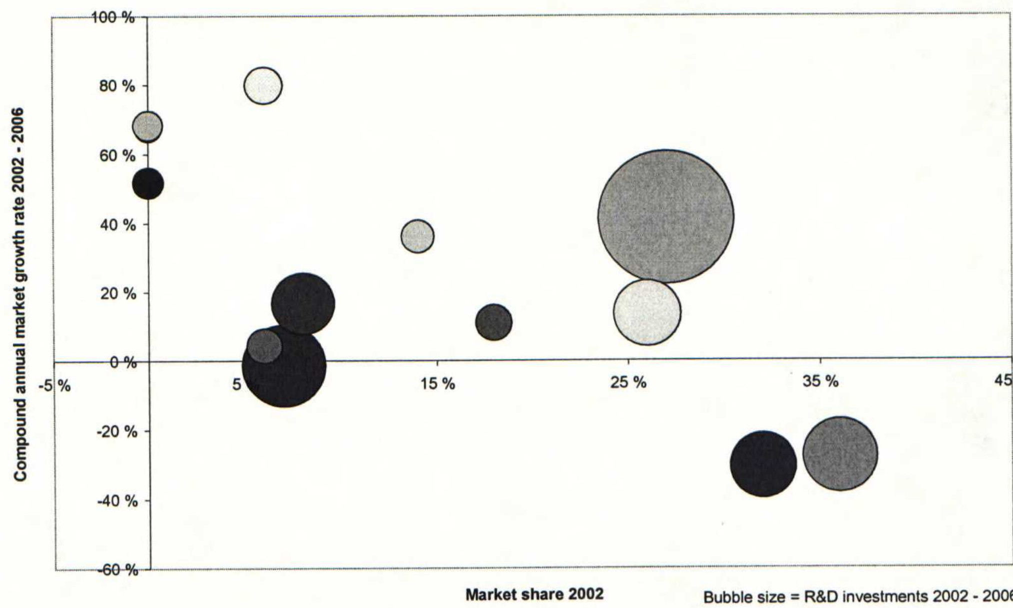


Figure 5-7 Market growth/market share matrix (Model 3)

Another manager commented that the market share and growth rate are not very reliable measures, as it is often more difficult to estimate the total market than the company's own sales. In addition, the market growth rate was seen problematic in considering new products, as the growth rate can be almost anything. Very high growth rates usually indicate new markets, which are typically small in size.

In general, however, the model was considered very useful. The model tied the highest overall grade with Model 2, although the reliability of the measures was considered lower. The model was also considered to be the second easiest to understand. This may be due to familiarity with the model as most managers mentioned that they had used the model before. On the other hand, one manager did not like the model because of his previous experiences.

Two alternative models were suggested in the interviews. Several managers found it useful to build a series of annual graphs, in which annual growth rates would be used instead of the compound growth rate over time. In addition, one manager would have also liked to see a graph in which the bubbles would have reflected the market potential instead of the size of the R&D investment.

Model 4

Model 4 was based on the idea that it would be useful to compare the annual investments and sales of individual projects. The projects that are presented in the same graph are similar in terms of maturity and project type so that meaningful comparison can be done. The model is illustrated in Figure 5-8.

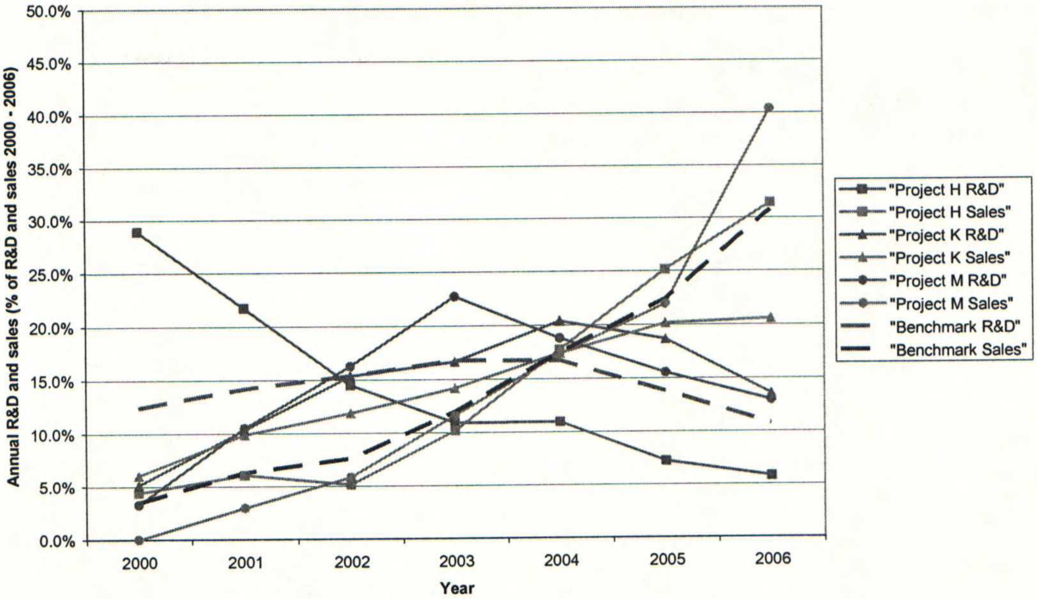


Figure 5-8 Annual distribution of projects' sales and R&D investments (Model 4)

The values on the vertical axis represent the relative share of a project's total sales or R&D investments that are realized during each year. For example, the R&D investments of Project H in year 2000 were nearly 30% of all the R&D investments in the project in years 2000 – 2006. The graph clearly shows that this project differs in this respect from the other projects.

The model also includes a benchmark level to ease the comparison of projects. The benchmark can be based on historical averages, averages of the projects shown, or averages of the industry. Unfortunately, industry-specific information could not be found during this study. In addition, the benchmark can be set by the management.

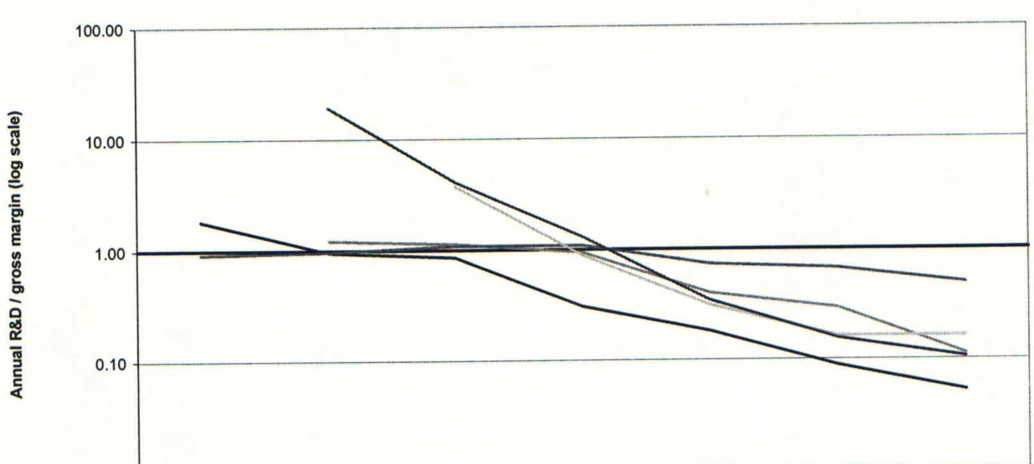
The idea of the model was considered to be useful. However, the model was relatively hard to understand, and it received the lowest overall grade.

Two alternatives for the model were suggested in the interviews. First, the model could be built so that the percentage each year would reflect a project's share of total sales or investments that year. Second, the model could be used to analyze one project at a time, so that it would be easier visually.

Model 5a – 5b

Model 5 is another model that compares projects that are similar in terms of maturity and project type. Two variations, Models 5a and 5b, were analyzed. Model 5a shows annual R&D investments divided by annual net sales. In Model 5b, annual gross margin is used as the denominator. The lower the ratio is, the more sales or gross margin is generated per each euro invested. More mature projects typically have lower ratios, as their R&D spending relative to sales is lower.

Figure 5-9 shows five projects, which are comparable in terms of project maturity. A general decreasing trend can be observed. When the ratio falls below one, more gross margin is generated than what is spent on the R&D of the project that year. A logarithmic scale is used because there are significant differences in the ratios. A table showing the ratios numerically is under the chart because it is difficult to see the exact values from the logarithmic scale. A target level or a benchmark could also be included in this graph, as in Model 4.



	2000	2001	2002	2003	2004	2005	2006
Project H	1.83	0.95	0.86	0.31	0.18	0.09	0.05
Project M	0.00	1.22	1.13	0.94	0.40	0.29	0.11
Project K	0.92	0.97	1.09	1.09	0.74	0.67	0.49
Project A	0.00	-2.93	3.73	0.89	0.31	0.16	0.16
Project D	0.00	19.10	4.10	1.30	0.35	0.15	0.10

Figure 5-9 Annual R&D investments of projects per annual gross margins (Model 5b)

Model 5 divided the opinions of the interviewed managers. Some managers considered the model very useful especially when considering more mature projects whose ratios are more stable. According to one manager, the model could help in deciding the correct investment level for projects that are meant to be cash cows. However, several managers did not consider the annual ratios to be very relevant.

Models 5a and 5b both received the same overall grade, which placed them tied to the tenth position.

As an alternative to the two models presented here, a cumulative model could also be used. In addition, contribution could be used as the denominator instead of sales or gross margin.

Model 6

Model 6 has its roots in the literature. The model in Figure 5-10 maps projects based on the probabilities of commercial success and technical success. The bubble sizes reflect the size of R&D investments. This kind of model was discussed in more detail in Section 4.3.

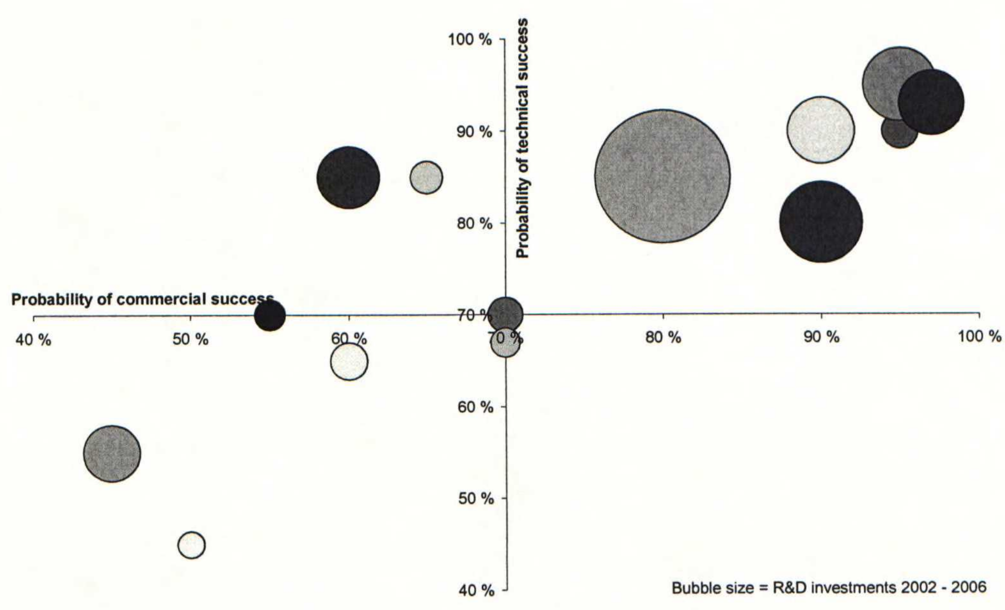


Figure 5-10 Projects' probabilities of technical and commercial success (Model 6)

Several managers, especially the most senior ones, considered this model extremely important. However, all managers realized the problems in estimating the probabilities. Therefore, the model tied with Model 5 for the tenth position in the overall grade.

As an alternative to this model, one manager suggested that the probability of commercial success could be switched to NPV. This way the model would become more reliable. In addition, sales could be used instead of R&D investments in the sizes of the bubbles.

Model 7

Model 7 illustrates how individual projects contribute to the total operating profit. The projects are sorted on the basis of their contribution from left to right, as shown in Figure 5-11. Project J on the left generates the most operating profit in absolute terms, whereas the last projects on the right actually contribute an operating loss. The columns are cumulative so that the last column indicates the total operating profit. The line, whose scale is on the secondary axis on the right, represents cumulative R&D investment.

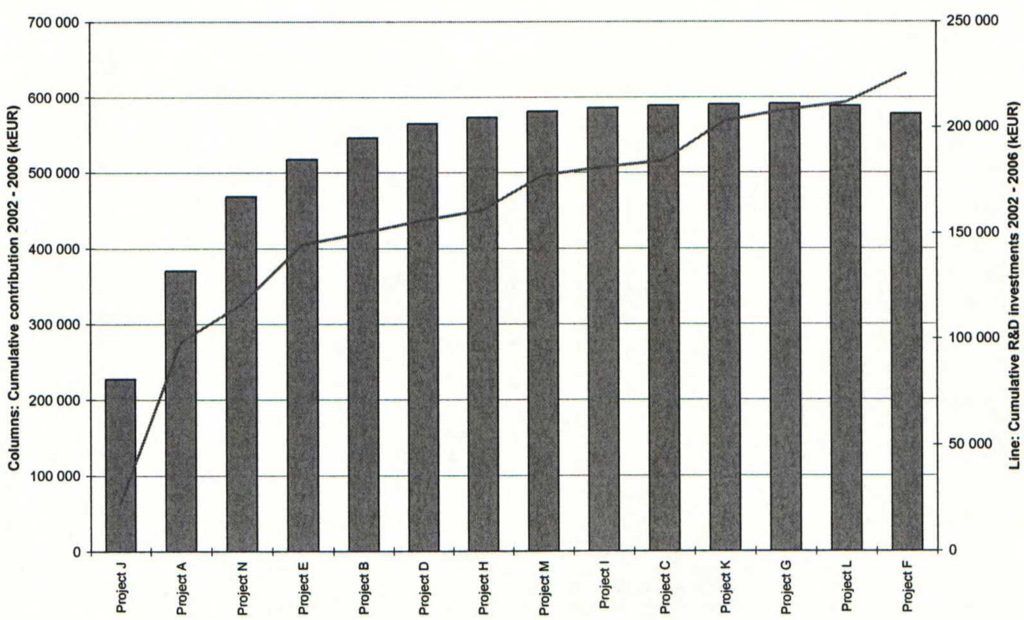


Figure 5-11 Projects sorted based on absolute profitability (Model 7)

According to the interviews, this model was considered to be the most relevant. However, its overall grade was only the sixth best. The model was considered a good starting point for making decisions on abandoning poor R&D projects although other models were considered necessary to support the decisions.

Three problems were identified. First, project interdependencies are not shown, which makes it more difficult to draw conclusions. Second, because the analysis is limited to the forecasting period, current projects tend be on the left and future projects on the right. This has to be realized or otherwise the model will lead to bad decisions. Third, the model is static; it does not show trends or when the contribution is actually generated.

One manager suggested an alternative version of the model, in which stacked columns would be used to show annual contributions.

Model 8

Model 8 is related to the previous model. In this model, projects are sorted on the ratio of operating profit to R&D investments as seen in Figure 5-12. The order of projects is usually different from Model 7 because the projects are sorted based on relative profitability, whereas in Model 7 the order is based on absolute profitability. Small projects, which provide a good return on investment, have a better ranking in this model. However, because both the relative profitability and absolute profitability are important, the managers saw these two models as complements to each other.

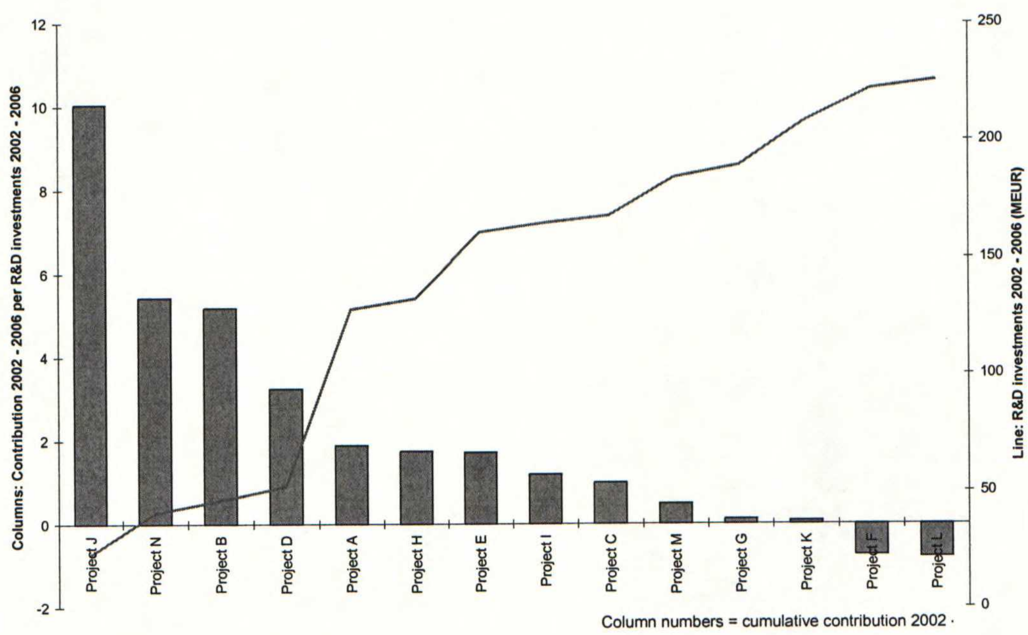


Figure 5-12 Projects sorted based on relative profitability (Model 8)

Model 8 was considered to be somewhat harder to understand than Model 7. However, the model received a better overall grade, which tied it for the third best position among all the models.

Model 9

Model 9 adds the dimension of real option value into portfolio analysis. The model divides the true NPV of projects into two components: basic NPV and the real option value as illustrated in Figure 5-13. As before, the bubble sizes reflect the size of R&D investments during the forecasting period.

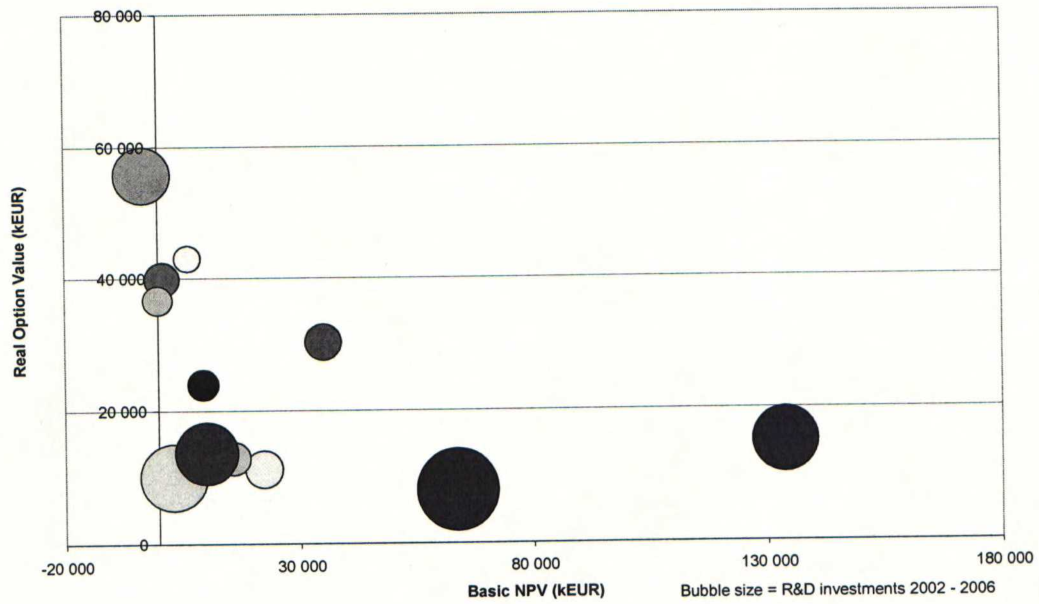


Figure 5-13 Real option value and basic NPV of projects (Model 9)

According to the interviews, the model illustrates well the more solid NPV value, and the value of managerial flexibility and future opportunities. However, some managers would have preferred a column graph, in which the basic NPV and the real option value would have been stacked over each other.

Although the managers accepted the use of real option value, real options made this model the second hardest to understand. In addition, the reliability of the model was considered low as the estimation of real option parameters, and especially the estimation of volatility, was seen as a difficult task. One manager feared that the model could be used in manipulating project attractiveness, as it may be easy to include too optimistic real option values. The overall grade placed this model in the tied eighth position.

One problem with this model was identified by Professor Laamanen. Because of capacity constraints, not all real options can be exercised. Especially if the real option values include values from growth options, the sum of individual growth options makes the model look too optimistic.

Model 10

The last model that was analyzed was Luehrman's (1998b) model, which was introduced in Section 4.5. The dimensions – value-to-cost and volatility – were difficult to understand for most of the managers. According to one manager, no decisions will be made on the basis of this model because it is too difficult to understand. In addition, volatility was seen as a very unreliable measure.

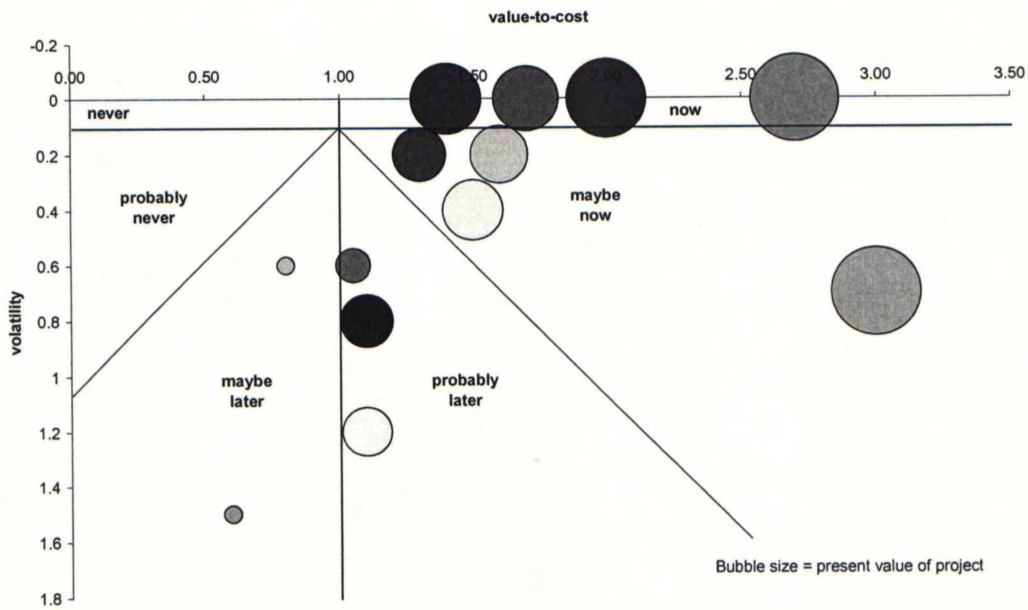


Figure 5-14 Luehrman's option space (Model 10)

The categorization of the option space was considered a positive aspect. One manager said that he likes the fact that a model dares to categorize projects because this will raise more discussion.

Luehrman's model was not considered to be optimal for the case company because it seems to be best applicable to projects that are in the early stages. The overall grade placed the model in the second last position.

Summary

At the end of each interview the managers were asked to select the portfolio models that they would be interested in using in a real decision-making situation. The maximum number of models that was allowed to be selected was set to three so that the managers had to prioritize some models over the others. The managers' selections are shown in Table 5-5. To respect the wishes of some of the managers, the respondents are shown in a random order.

Table 5-5 Portfolio models selected by the respondents[18]

Portfolio model	Respondent 1	2	3	4	5	6	7	Selections in total
1	X			X	X			3
2		X			X	X		3
3		X	X	X		X	X	5
4								0
5	X		X					2
6						X	X	2
7		X	X	X				3
8	X						X	2
9					X			1
10				X				1

An interesting observation is that all the portfolio models – with the exception of Model 4 – were selected at least once, and only Model 3 was chosen by the majority of the respondents. This could reflect the difficulty many respondents had in limiting their choices to three. For example, one manager stated that he would have chosen all but two models.[19] The results could also imply that the managers selected the models that are the most useful in the particular position of each manager. A senior manager may benefit from different models than a junior manager. In addition, a senior manager may think less how a model can be implemented in practice than a junior manager.

The results also give support to the presumption that one has to use several models instead of only one. Several models are needed in the decision making process because no single model can include all the important dimensions.

Table 5-6 summarizes the grades given by the managers. Based on the ranking by the overall grade, Models 2 and 3 were considered the best. However, when considering the grades together with the results of the previous table, no clear total ranking of models can be made. A more detailed table showing the grade distribution is in Appendix A.

[18] Respondent 4 did not want to limit his selections below four.

[19] The manager would not have selected models 2 and 4.

Table 5-6 Grading of the portfolio models

Portfolio model	Average grading (1 = worst, 5 = best)				Rank by overall grade
	Easy to understand	Relevant	Reliable	Overall grade	
1a	3.7	4.0	3.3	3.6	3
1b	3.7	3.7	3.6	3.3	8
1c	3.6	3.9	3.0	3.6	3
1d	3.0	3.6	3.1	3.4	6
2	4.7	4.0	3.4	3.7	1
3	4.4	4.0	2.9	3.7	1
4	3.3	3.6	3.3	3.0	14
5a	3.7	3.3	3.4	3.1	10
5b	3.7	3.7	3.3	3.1	10
6	3.9	3.9	2.4	3.1	10
7	4.4	4.4	3.4	3.4	6
8	3.6	4.3	3.3	3.6	3
9	2.7	3.7	2.1	3.3	8
10	2.1	3.6	2.6	3.1	13

Project interdependencies and scenario analysis

This last subsection discusses two topics which are relevant when using the presented portfolio models in the case company. The first topic is project interdependencies, and the second is scenario analysis.

In the interviews, many managers raised the concern that portfolio models do not explicitly show the interdependencies of projects. For instance, some projects may be needed to support other projects, or the success of some projects may affect, negatively or positively, other projects. Interdependencies such as these could be shown in portfolio models by using relational arrows or by identifying related projects with colors.

Figure 5-15 shows what Model 3 could look like if project interdependencies were shown explicitly with arrows. Here, a two-headed arrow signals that two projects depend on each other, a single arrow indicates that a project depends on another project but not vice versa, and a lightning-shaped arrow illustrates that a project may cannibalize another project.

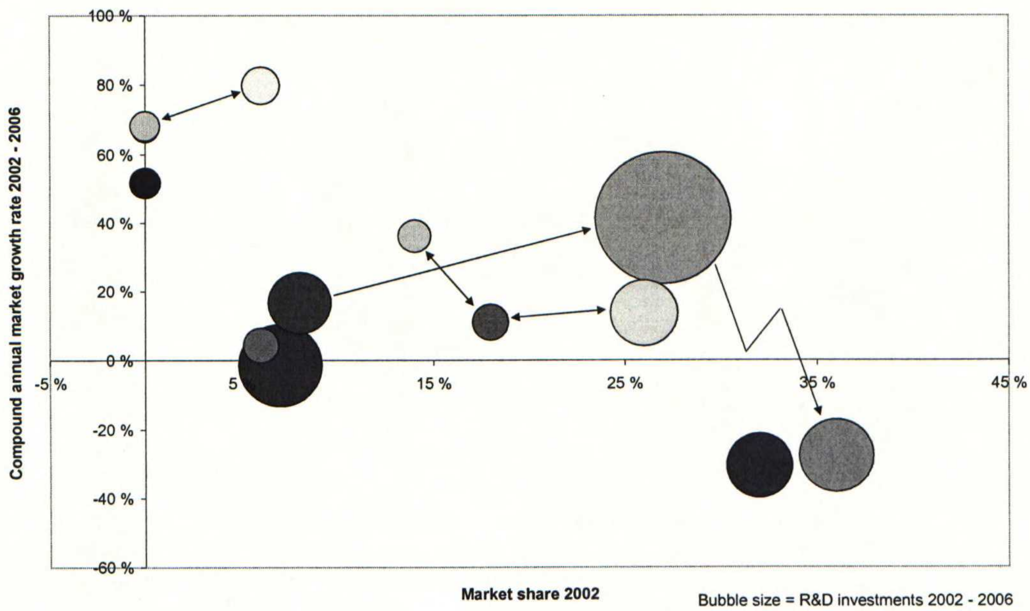


Figure 5-15 Illustration of project interdependencies in a portfolio model

Cannibalization is an important form of project interdependency. It means that new products steal sales from current products. Therefore, when evaluating an R&D project, the net loss on cannibalized sales should be deducted from project revenue. However, according to Crawford and Di Benedetto (2003, p. 247), some experts omit the loss because they believe that if the company does not do this itself, a competitor will.

As was explained in the previous section, the case company produces several future scenarios that show the value of a project based on different assumptions. These scenarios can also be extremely valuable in portfolio models. Models drawn for each different scenario can be compared and thus valuable new information is available to decision-makers. Scenarios allow the managers to see the sensitivity of the portfolio balance to changes in the underlying assumptions.

6 Discussion and Conclusions

The purpose of this study was to analyze the practical usefulness of real options and portfolio models in R&D project selection. A thorough literature study was conducted in order to support the development of the models. The models were constructed iteratively so that frequent feedback was received and used in the further development. Finally, the models were implemented in practice and seven managers of the case company were interviewed to draw conclusions on the models.

6.1 Results of the Study

According to Pike (1997), only a handful of articles have analyzed actual case studies on real options, and most of the case studies that have been published have covered the oil or pharmaceutical industry. Therefore, this study makes a contribution by presenting a real option model for staged R&D investments in a high technology environment.

The model that was developed faced the same difficulties as identified in the literature by, for example, Davis (1998) and Luehrman (1998a). Especially the estimation of volatility had to be done in an ad hoc manner: the study developed a novel technique to approximate the volatility by using cash flow scenarios. Even if some of the assumptions made in the model are not realistic, the results still yield some insights, although the numbers become less reliable.

It became evident that many of the sophisticated real option techniques presented in literature are too complex and hard to understand by practitioners. Therefore, the developed model had to sacrifice some accuracy in order to be easier to understand and accepted.

The portfolio models that were developed and analyzed added real value to the case company because some of them were implemented already during the research process. These models may also be useful in other organizations, as long as they are selected carefully to meet the needs of each specific organization.

The combination of real option valuation and portfolio models was not as promising as initially expected. Luehrman's (1998b) model was the only portfolio model using real option thinking that was found in literature. This study used the real option value in portfolio models to complement the basic financial calculations.

Out of the ten models that were analyzed in the interviews, there was no model that was clearly the best. In contrast, the results suggest that no one model can give the right answer to the R&D project selection problem because an organization must consider many factors when evaluating its R&D portfolio. Therefore, decision-making can best be improved by using several models, which are tailored to specific needs and which give a many-sided view of the portfolio. This result gets support from literature. For example, Cooper et al. (1998, p. 18) conclude that no company among the numerous companies they interviewed had totally resolved the project portfolio management problem. In addition, they were unable to find a dominant model.

The interviews showed that no decision will be made based on models that cannot be understood. This puts pressure on researchers that seem to be developing models of growing complexity. As already explained, this study put the practical usefulness first.

Finally, an interesting observation, which was made during the research, is that the results R&D project selection models give may not be as important as the process of using the models. Several other studies (see, e.g., Bard et al. 1988) have also concluded that the most value is often derived from systematically going through the projects and assessing them.

6.2 Limitations

No studies are without limitations. This section discusses the main limitations of the present study.

The real option valuation model and the portfolio models described in the study were constructed for a specific case company. Although the case company's positive response to these models suggests that such models are useful in practical R&D project selection, the models itself may not be directly applicable in other organizations. Models need to reflect the strategy and the dimensions that are the most relevant in a particular organization. Therefore, models developed for one organization may not support decision-making in others. On the other hand, a collection of models found useful in one organization can be a good starting point for the development work in another.

The R&D projects that were in the focal portfolio included projects that had already passed the earliest project phases. Consequently, the portfolio models were not developed to analyze projects in the ideation or concept phase and, hence, the results of the study cannot be directly applied to such projects. According to Tritle et al. (2000), measures typically vary over different phases of an R&D project. In the early phases the emphasis should be more on strategic fit and not so much on financial dimensions that dominated the models presented in this study.

This study focused on only one part of the R&D investment process, namely the R&D project selection. The selected scope limits the usefulness of the results, as the models are unlikely to work up to their full potential unless the whole capital investment process supports their use. This study ignored the important linkages to the process, as well as the important social aspects that are present in the process.

6.3 Recommendations for Further Research

Real options and portfolio models may significantly help managers in making capital investment decisions. This study examined the selection of one particular type of capital investments – namely, R&D investments – in one organization. Possible further studies could examine other types of capital investments and especially capital investments in other organizations. The findings of this study can be used to guide such further studies.

The real option model developed in this study was intentionally a simple one, as real options were a novel concept to most practitioners in the case company. However, more research attention could be given to making a more sophisticated model when the practitioners get comfortable with the easier one. The more sophisticated model could include other real option types, such as growth options that are relevant in R&D project selection. However, care needs to be taken in order to keep the model on an understandable level.

Finally, further research is needed on the topic of project interdependencies. The interviews revealed that investment or disinvestment decisions cannot be made without understanding the project relationships. The incorporation of project interdependencies into portfolio models is not a simple task but, if properly carried out, it would significantly improve the value of the models.

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Appendix A

Distribution of grades given to portfolio models

(1 = worst, 5 = best, DK = "don't know")

Port-folio model	Easy to understand						Relevant						Reliable						Overall grade					
	1	2	3	4	5	DK	1	2	3	4	5	DK	1	2	3	4	5	DK	1	2	3	4	5	DK
1a			2	5				1	1	2	3				5	2					3	4		
1b			2	5					2	5					3	4				1	3	3		
1c			3	4				1	1	3	2			2	3	2					3	4		
1d		2	3	2					3	4					6	1				1	2	4		
2				2	5				1	5	1				4	3					2	5		
3				4	3			2		1	4			2	4	1				1		6		
4		2	3		2			1	2	3	1			1	3	3				1	5	1		
5a		1	1	4	1			2	2	2	1			1	2	4				2	2	3		
5b		1	1	4	1			2		3	2			1	3	3				2	3	1	1	
6		1	1	3	2			2		2	3		1	2	4				1	1	1	4		
7				4	3				1	2	4				4	3				2	1	3	1	
8		2	1	2	2				1	3	3				5	2				1	2	3	1	
9		3	3	1					2	5				6	1						5	2		
10	2	2	3						3	4				4	2	1				2	2	3		